

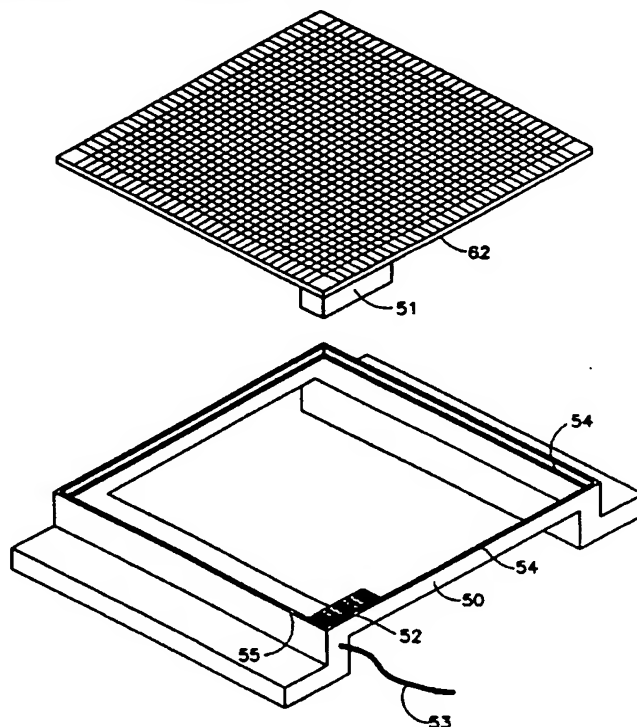
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(54) Title: IMPEDANCE IMAGING DEVICES AND MULTI-ELEMENT PROBE



## (57) Abstract

A multi-element probe for providing an electrical connection to a tissue surface comprising: a plurality of individual conductive sensing elements (62), each having a front portion suitable for contact with the tissue surface, a plurality of conductive elements (51, 52) providing an electrical connection to the respective individual sensing elements and a partition or spacing separating the individual sensing elements such that when the individual probes contact the tissue surface they are substantially isolated from each other.

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## IMPEDANCE IMAGING DEVICES AND MULTI-ELEMENT PROBE

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FIELD OF THE INVENTION

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The present invention relates to systems for imaging based on the measurement of electrical potentials at an array of points, especially on the skin or other tissue surface of a patient.

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BACKGROUND OF THE INVENTION

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The measurement of electrical potentials on the skin has many uses. For example, electrocardiograms are derived from measuring the potential generated by the heart of a patient at various points on the skin.

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Skin potentials are also measured in apparatus for determining the electrical impedance of human tissue, including two-dimensional (e.g., U.S. Patents 5,063,937, 4,291,708 and 4,458,694) or three-dimensional (e.g., U.S. Patents 4,617,939 and 4,539,640) mapping of the tissue impedance of the body. In such systems an electrical potential is introduced at a point or points on the body and measured at other points at the body. Based on these measurements and on algorithms which have been developed over the past several decades, an impedance map or other indication of variations in impedance can be generated.

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U.S. Patents 4,291,708 and 4,458,694 and "Breast Cancer screening by impedance measurements" by G. Piperno et al. Fontiers Med. Biol. Eng., Vol. 2, No. 2, pp 111-117, the disclosures of which are incorporated herein by reference, describe systems in which the impedance between a point on the surface of the skin and some reference point on the body of a patient is determined. These references describe the use of a multi-element probe for the detection of cancer, especially breast cancer, utilizing detected variations of impedance in the breast.

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In these references a multi-element probe is described in which a series of flat, stainless steel, sensing elements are mounted onto a PVC base. A lead wire is connected between each of these elements and detector circuitry. Based

1 on the impedance measured between the elements and a remote  
2 part of the body, signal processing circuitry determines the  
3 impedance variations in the breast. Based on the impedance  
4 determination, tumors, and especially malignant tumors, can  
5 be detected.

6 The multi-element probe is a critical component in this  
7 system and in other systems which use such probes. On one  
8 hand the individual elements must make good contact with the  
9 skin and with the corresponding points on the sensing or  
10 processing electronics while also being well isolated from  
11 each other. On the other hand, use of gels to improve skin  
12 contact carries the risk of cross-talk, dried gel build-up  
13 on the elements and inter-patient hygienic concerns.

14 A paper titled "Capacitive Sensors for IN-Vivo  
15 Measurements of the Dielectric Properties of Biological  
16 materials" by Karunayake P.A.P. Esselle and Stanislaw S.  
17 Stuchly (IEEE Trans. Inst & Meas. Vol. 37, No. 1, p. 101-  
18 105) describes a single element probe for the measurement of  
19 in vivo and in vitro measurements of the dielectric  
20 properties of biological substances at radio and microwave  
21 frequencies. The sensor which is described is not suitable  
22 for impedance imaging.

23 A paper entitled "Messung der elektrischen Impedance  
24 von Organen- Apparative Ausrüstung für Forschung und  
25 klinische Anwendung" by E. Gersing (Biomed. Technik 36  
26 (1991), 6-11) describes a system which uses single element  
27 impedance probes for the measurement of the impedance of an  
28 organ. The device described is not suitable for impedance  
29 imaging.

30 A Paper titled "MESURE DE L'IMPEDANCE DES TISSUS  
31 HEPATIQUELES TRANSFORMES PAS DES PROCESSUS LESIONELS" by J.  
32 Vrana et al. (Ann. Gastroentrol. Hepetol., 1992, 28, no. 4,  
33 165-168) describes a probe for assessing deep tissue by use  
34 of a thin injection electrode. The electrode was positioned  
35 by ultrasound and specimens were taken for cytological and  
36 histological assessment. The electrode was constituted on a

1 biopsy needle used to take the samples.

2 A paper titled "Continuous impedance monitoring during  
3 CT-guided stereotactic surgery: relative value in cystic and  
4 solid lesions" by V. Rajshekhar (British Journal of  
5 Neurosurgery (1992) 6, 439-444) describes using an impedance  
6 probe having a single electrode to measure the impedance  
7 characteristics of lesions. The objective of the study was  
8 to use the measurements made in the lesions to determine the  
9 extent of the lesions and to localize the lesions more  
10 accurately. The probe is guided to the tumor by CT and four  
11 measurements were made within the lesion as the probe passed  
12 through the lesion. A biopsy of the lesion was performed  
13 using the outer sheath of the probe as a guide to position,  
14 after the probe itself was withdrawn.

15 A paper titled "Rigid and Flexible Thin-Film Multi-  
16 electrode Arrays for Transmural Cardiac Recording" by J. J.  
17 Mastrototaro et al. (IEEE TRANS. BIOMED. ENG. Vol. 39, No.  
18 3, March 1992, 271-279) describes a needle probe and a flat  
19 probe each having a plurality of electrodes for the  
20 measurement of electrical signals generated in the heart.

21 A paper entitled "Image-Based Display of Activation  
22 Patterns Derived from Scattered Electrodes" by D. S. Buckles  
23 et al. (IEEE TRANS. BIOMED ENGR. Vol. 42, No. 1, January  
24 1995, 111-115) describes a system for measurement of  
25 electrical signals generated on the heart by use of an array  
26 of electrodes on a substrate. The heart with the electrodes  
27 in place is viewed by a TV camera and an operator marks the  
28 positions of the electrodes on a display. The system then  
29 displays the heart (as visualized prior to the placement of  
30 the electrodes) with the position markings.

31 A paper entitled "Development of a Multiple Thin-Film  
32 Semimicro DC-Probe for Intracerebral Recordings" by G. A.  
33 Urban et al. (IEEE TRANS. BIOMED ENGR. Vol. 37, No. 10,  
34 October 1990, 913-917) describes an elongate alumina ceramic  
35 probe having a series of electrodes along its length and  
36 circumference for measuring functional parameters

1 (electrical signals) in the brain. Electrophysiological  
2 recording, together with electrosimulation at the target  
3 point during stereotactic surgery, was performed in order to  
4 ensure exact positioning of the probe after stereotactic  
5 calculation of the target point. Bidimensional X-Ray imaging  
6 was used in order to verify the exact positioning of the  
7 electrode tip.

8 SUMMARY OF THE INVENTION

9 It is an object of certain aspects of the invention to  
10 provide a multi-element probe having improved and more  
11 uniform and repeatable contact with the skin with minimal  
12 operator expertise and minimal risk of cross-patient  
13 contamination.

14 It is an object of certain aspects of the invention to  
15 provide improved inter-element electrical isolation, and to  
16 permit sliding of the probe while it is urged against the  
17 skin.

18 It is an object of certain aspects of the invention to  
19 provide a relatively inexpensive disposable multi-element  
20 probe.

21 It is an object of certain aspects of the invention to  
22 provide a multi-element probe having sufficient transparency  
23 to allow for viewing of tissue surface features and to allow  
24 for referencing the probe with respect to physical features  
25 of or on the skin.

26 It is an object of certain aspects of the invention to  
27 provide a method of distinguishing between artifacts and  
28 abnormalities.

29 It is an object of certain aspects of the invention to  
30 provide a system for electrical impedance imaging which  
31 simultaneously acquires, uses and preferably displays both  
32 capacitance and conductance information.

33 It is an object of certain aspects of the invention to  
34 provide a system for electrical impedance testing of the  
35 breast or other body region which provides more accurate  
36 information regarding the position of impedance

1 abnormalities detected in the breast or other region.

2 It is an object of certain aspects of the invention to  
3 provide for electrical impedance testing with a variable  
4 spatial resolution.

5 It is an object of certain aspects of the invention to  
6 provide for two dimensional electrical impedance testing  
7 giving an indication of the distance of an abnormality from  
8 the surface of the skin.

9 It is an object of certain aspects of the invention to  
10 provide apparatus especially suitable for breast impedance  
11 measurements.

12 It is an object of certain aspects of the invention to  
13 provide guidance for placement of elongate objects such as  
14 biopsy needles, localization needles, fiber optic endoscopes  
15 and the like using real time and/or recorded stereotactic  
16 images to guide the object.

17 It is a further object of certain aspects of the  
18 invention to provide a biopsy needle having an impedance  
19 measuring function to aid in the taking of a biopsy.

20 It is an object of certain aspects of the invention to  
21 provide more direct comparison between the results of  
22 electrical impedance maps and the results of optical,  
23 ultrasound or other imaging modalities.

24 It is an object of certain aspects of the invention to  
25 provide apparatus and method for indicating, on an  
26 anatomical illustration, the location and region from which  
27 an impedance image, shown together with the illustration is  
28 derived.

29 It is an object of certain aspects of the invention to  
30 provide apparatus which facilitates direct comparison  
31 between X-Ray and impedance mammographic images, as for  
32 example by superposition of the images.

33 It is an object of certain aspects of the invention to  
34 provide a method of determining a multi-frequency impedance  
35 map.

36 It is an object of certain aspects of the invention to

1 optimize the impedance mapping utilizing a pulsed voltage  
2 excitation.

3 It is an object of certain aspects of the invention to  
4 provide palpation and tactile sensing of an area while  
5 simultaneously providing an impedance image of the area.

6 In general, the term "skin" as used herein means the  
7 skin or other tissue of a subject.

8 There is therefore provided, in accordance with a  
9 preferred embodiment of the invention, a multi-element probe  
10 for providing an electrical connection to a tissue surface,  
11 comprising:

12 a plurality of individual conductive sensing elements,  
13 each having a front portion suitable for contact with the  
14 tissue surface;

15 a plurality of conductive elements providing an  
16 electrical connection to the respective individual sensing  
17 elements; and

18 a partition separating the individual sensing elements  
19 such that, when the sensing elements contact the tissue  
20 surface, the sensing elements are substantially electrically  
21 isolated from each other.

22 Preferably, the sensing elements comprise a conductive,  
23 viscous gel. Alternatively or additionally, in a preferred  
24 embodiment of the invention, the sensing elements comprise a  
25 conductive, flexible, solid.

26 Alternatively or additionally, in a preferred  
27 embodiment of the invention the sensing elements comprise a  
28 sponge impregnated with a conductive viscous gel.

29 In a preferred embodiment of the invention, each  
30 individual sensing element is located in a well formed by  
31 the partition and a substrate underlying the sensing  
32 element.

33 Preferably, the side of the substrate opposite the  
34 sensing elements is formed with indentations for aligning  
35 the multi-element probe.

36 In a preferred embodiment of the invention, the well is

1 formed by embossing the partition on a sheet of material,  
2 whereby the un-embossed portion of the sheet forms the  
3 substrate underlying the sensing element. Preferably, the  
4 indentations are the back of the embossed wells.

5 In an alternative preferred embodiment of the  
6 invention, the well is formed by laminating a grid formed by  
7 holes punched in a sheet or formed by extrusion to the  
8 substrate.

9 Alternatively, the well is formed by printing the  
10 partitions onto the substrate.

11 In a preferred embodiment of the invention, there is an  
12 electrical connection between a first surface of the  
13 substrate inside the well and a second, opposite, surface of  
14 the substrate. Preferably the apparatus also comprises an  
15 anisotropic conductive sheet overlying the second surface of  
16 the substrate.

17 Alternatively the probe preferably comprises a  
18 conductive contact on the second surface of the substrate  
19 which is electrically connected to the first surface of the  
20 substrate and an adhesive contact overlying the conductive  
21 contact.

22 In a preferred embodiment of the invention, the sensing  
23 elements do not extend past the top of the partition or do  
24 not extend to the top of the partition.

25 In a preferred embodiment of the invention the probe  
26 includes a cover having a conductive surface facing the  
27 front portion of the sensing elements.

28 There is further provided in accordance with a  
29 preferred embodiment of the invention, a multi-element probe  
30 for providing an electrical connection to tissue,  
31 comprising:

32 a plurality of individual conductive sensing elements,  
33 each having a front portion suitable for contact with the  
34 tissue;

35 a plurality of conductive elements providing an  
36 electrical connection to the respective individual sensing

1 elements; and

2 a cover having a surface facing the front portion of  
3 the sensing elements, at least that portion of said surface  
4 facing the sensing elements being an electrically conductive  
5 surface.

6 Preferably, the cover is formed of a flexible material  
7 and wherein, in an unstressed position said electrical  
8 conductive surface does not contact said conductive sensing  
9 elements. In a preferred embodiment of the invention, the  
10 cover is so configured that the surface contacts the sensing  
11 elements when a surface of the cover opposite the conductive  
12 surface is pressed toward the sensing elements.

13 In a preferred embodiment of the invention, the cover  
14 also includes an area, on the surface facing the individual  
15 sensing elements, remote from the individual sensing  
16 elements, which is a conductive area electrically connected  
17 to said portions facing the sensing elements, the multi-  
18 element probe also including a contact electrically  
19 connected to the exterior of the probe. Preferably, in an  
20 unstressed position said electrical conductive surface does  
21 not contact said contact and wherein said cover is so  
22 configured that the conductive area contacts the contact  
23 when a surface of the cover opposite the conductive surface  
24 is pressed toward the sensing elements.

25 In a preferred embodiment of the invention the probe  
26 comprises at least one contact suitable for connection to an  
27 external source of electrical energy and also including  
28 impedance elements between the conductive surfaces opposite  
29 the sensing elements and the contact.

30 Preferably the cover includes impedance elements  
31 between the conductive surfaces opposite the sensing  
32 elements and the contact.

33 There is further provided, in accordance with a  
34 preferred embodiment of the invention, a multi-element probe  
35 for providing an electrical connection to a tissue surface  
36 comprising:

1 a plurality of individual conductive sensing elements,  
2 each having a front portion suitable for contact with the  
3 tissue surface; and

4 a plurality of conductive elements providing an  
5 electrical connection to the respective individual sensing  
6 elements,

7 wherein the side of the substrate opposite the sensing  
8 elements is formed with indentations for aligning multi-  
9 element probe.

10 There is further provided, in accordance with a  
11 preferred embodiment of the invention, a multi-element probe  
12 for the measurement of impedance of tissue, wherein the  
13 elements of the probe are sufficiently transparent to allow  
14 visualization of tissues beneath the probe when the probe is  
15 place in contact with the tissues.

16 There is further provided, in accordance with a  
17 preferred embodiment of the invention, a multi-element probe  
18 for providing an electrical connection to a tissue surface  
19 comprising:

20 a plurality of individual conductive sensing elements,  
21 each having a front portion suitable for contact with the  
22 tissue surface; and

23 a plurality of conductive elements providing an  
24 electrical connection to the respective individual sensing  
25 elements, wherein

26 the elements of the probe are sufficiently transparent  
27 to allow visualization of tissues beneath the probe when the  
28 probe is place in contact with the tissues.

29 Preferably, the sensing elements are formed of a spongy  
30 conductive material.

31 There is further provided, in accordance with a  
32 preferred embodiment of the invention a multi-element probe  
33 for providing an electrical connection to a tissue surface  
34 comprising:

35 a plurality of individual conductive sensing elements,  
36 each having a front portion suitable for contact with the

1 tissue surface; and

2 a plurality of conductive elements providing an  
3 electrical connection to the respective individual sensing  
4 elements,

5 wherein the sensing elements are formed of a spongy  
6 conductive material.

7 Preferably, the sensing elements are formed on a  
8 flexible surface, whereby the multi-element probe conforms,  
9 at least in part, to the tissue.

10 Preferably, the probe is provided with apertures  
11 between sensing elements suitable for the passage of a thin  
12 elongate object.

13 There is further provided, in accordance with a  
14 preferred embodiment of the invention, a multi-element probe  
15 for providing an electrical connection to a tissue surface  
16 comprising:

17 an array of individual conductive sensing elements  
18 spaced over a surface, each element having a front portion  
19 suitable for contact with the tissue surface; and

20 a plurality of conductive elements providing an  
21 electrical connection to the respective individual sensing  
22 elements,

23 wherein the area of the conductive elements comprises  
24 less than 50% of the total area encompassed by the array.

25 There is further provided, in accordance with a  
26 preferred embodiment of the invention a multi-element probe  
27 for providing an electrical connection to a tissue surface  
28 comprising:

29 a plurality of individual conductive sensing elements,  
30 each having a front portion suitable for contact with the  
31 tissue surface; and

32 a plurality of conductive elements providing an  
33 electrical connection to the respective individual sensing  
34 elements,

35 wherein the probe is provided with apertures between  
36 sensing elements suitable for the passage of a thin elongate

1 object.

2 Preferably, at least a portion of the surface of the  
3 probe facing the tissue to be measured is adhesive to the  
4 tissue.

5 There is further provided, in accordance with a  
6 preferred embodiment of the invention a multi-element probe  
7 for providing an electrical connection to a tissue surface  
8 comprising:

9 a plurality of individual conductive sensing elements,  
10 each having a front portion suitable for contact with the  
11 tissue surface; and

12 a plurality of conductive elements providing an  
13 electrical connection to the respective individual sensing  
14 elements,

15 wherein at least a portion of the surface of the probe  
16 facing the tissue to be measured is adhesive to the tissue.

17 In a preferred embodiment of the invention, the probe  
18 further includes:

19 means for attaching the probe to the finger of a  
20 person whereby the person can perform palpative examination  
21 concurrently with impedance imaging.

22 There is further provided, in accordance with a  
23 preferred embodiment of the invention a multi-element probe  
24 for providing an electrical connection to a tissue surface  
25 comprising:

26 a plurality of individual conductive sensing elements,  
27 each having a front portion suitable for contact with the  
28 tissue surface; and

29 a glove having fingers, said sensing elements being  
30 attached to the outside of one of the glove at one of the  
31 fingers whereby a wearer of the glove can perform palpative  
32 examination concurrently with impedance imaging.

33 There is further provided, in accordance with a  
34 preferred embodiment of the invention, a multi-element  
35 intermediate device for providing an electrical connection  
36 between a multiconductor sensor device and a tissue surface

1 comprising a plurality of individual conductive sensing  
2 element, electrically insulated from each other, each having  
3 a front portion suitable for contact with the tissue surface  
4 and a back portion detachably matable to the multi-conductor  
5 sensor device.

6 Preferably, the intermediate device includes electrical  
7 contacts on the back portion which are electrically  
8 connected to the sensing element and which contact a  
9 plurality of mating contacts on the multi-conductor sensor  
10 device.

11 There is further provided, in accordance with a  
12 preferred embodiment of the invention a catheter or  
13 endoscopic probe comprising:

14 a multi-element probe as described above; and  
15 a fiber optic viewer whose field of view includes at  
16 least one surface of the probe when the probe is in contact  
17 with the tissue.

18 There is further provided, in accordance with a  
19 preferred embodiment of the invention a catheter or  
20 endoscopic probe comprising:

21 a multi-element probe for providing an electrical  
22 connection to a tissue surface, the probe including a  
23 plurality of individual conductive sensing elements on a  
24 substrate, each sensing element having a front portion  
25 suitable for contact with the tissue surface and fiduciary  
26 marks visible from an other surface; and

27 a fiber optic viewer whose field of view includes at  
28 least the other surface of the probe.

29 There is further provided, in accordance with a  
30 preferred embodiment of the invention a biopsy needle  
31 having:

32 a leading end for insertion into tissue to undergo  
33 biopsy and an elongated outer surface; and

34 at least one impedance sensing element formed on said  
35 outer surface which provides electrical connection to  
36 tissue during biopsy.

1        Preferably, the at least one sensing element comprises  
2 a plurality of sensing elements electrically insulated from  
3 each other and spaced along the length of the outer surface.

4        Alternatively or additionally, the at least one sensing  
5 element preferably comprises a plurality of sensing elements  
6 electrically insulated from each other and spaced along the  
7 circumference of the outer surface.

8        In a preferred embodiment of the invention, at least  
9 one sensing element comprises a plurality of sensing  
10 elements electrically insulated from each other and forming  
11 a matrix of elements spaced along the length and  
12 circumference of the outer surface.

13       There is further provided, in accordance with a  
14 preferred embodiment of the invention apparatus for  
15 impedance imaging of a breast comprising:

16       a multi-element probe comprising a plurality of sensing  
17 elements and adapted for mounting on one side of a breast;

18       an electrode adapted for mounting on a side of the  
19 breast substantially opposite the multi-element probe; and

20       a source of electrical energy which provides a voltage  
21 between at least a portion of the electrode and at least one  
22 element of the probe.

23       There is further provided, in accordance with a  
24 preferred embodiment of the invention apparatus for  
25 impedance imaging of a breast comprising:

26       a multi-element probe comprising a plurality of sensing  
27 elements and adapted for mounting on one side of a breast;

28       an electrode adapted for mounting on a side of the  
29 breast substantially opposite the multi-element probe;

30       an additional electrode adapted for mounting on portion  
31 of the body remote from the breast; and

32       a source of electrical energy which provides a voltage  
33 between the additional electrode and at least one element of  
34 the probe.

35       Preferably, the multi-element probe and the electrode  
36 adapted for mounting on a side of the breast form respective

1 parallel planes.

2 Alternatively, in a preferred embodiment of the  
3 invention, the multi-element probe and the electrode adapted  
4 for mounting on a side of the breast form two planes at an  
5 angle to each other.

6 Preferably, the apparatus includes a plurality of  
7 receivers which measure an electrical signal at the sensing  
8 elements.

9 In a preferred embodiment of the invention, the  
10 electrode is adapted for mounting on a side of the breast  
11 comprises a second multi-element probe.

12 Preferably, at least one of the multi-element probes is  
13 non-planar to conform to the shape of the breast. The non-  
14 planar array can be either rigid or flexible.

15 Alternatively or additionally at least one of the  
16 multi-element probes is flexible so as to conform to the  
17 shape of the breast.

18 There is further provided, in accordance with a  
19 preferred embodiment of the invention, apparatus for  
20 impedance imaging of a breast comprising:

21 a first multi-element probe comprising a plurality of  
22 sensing elements and adapted for mounting on one side of a  
23 breast;

24 a second multi-element probe adapted for mounting on a  
25 side of the breast substantially opposite the multi-element  
26 probe; and

27 a source of electrical energy which alternatively  
28 energizes at least some of the elements of one or the other  
29 of the first and second multi-element probes by supplying a  
30 voltage thereto, wherein the unenergized one of the multi-  
31 element probes forms an image based on the voltage applied  
32 to the energized probe.

33 There is further provided, in accordance with a  
34 preferred embodiment of the invention apparatus for  
35 impedance imaging of tissue comprising:

36 an impedance probe which produces signals

1 representative of impedance values sensed by the elements  
2 and having fiduciary marks which are visible when the probe  
3 contacts the tissue;

4 an impedance image generator which receives the signals  
5 and produces an impedance image;

6 a video camera which views the probe and tissue and  
7 generates a video image; and

8 a video image processor which receives a video image of  
9 the tissue without the probe in place and an image of the  
10 tissue with the probe in place, and provides a video image  
11 of the tissue with the fiduciary marks and impedance image  
12 superimposed thereon.

13 There is further provided, in accordance with a  
14 preferred embodiment of the invention a method of impedance  
15 imaging of the breast comprising:

16 (a) positioning a multi-element probe, comprising a  
17 plurality of sensing elements, on one side of the breast;

18 (b) positioning an electrode on a side of the breast  
19 substantially opposite the multi-element probe;

20 (c) electrifying the electrode; and

21 (d) measuring a signal at at least some of the elements  
22 of the multi-element probe.

23 There is further provided, in accordance with a  
24 preferred embodiment of the invention a method of impedance  
25 imaging of the breast comprising:

26 (a) positioning a multi-element probe, comprising a  
27 plurality of sensing elements, on one side of the breast;

28 (b) positioning an electrode on a side of the breast  
29 substantially opposite the multi-element probe;

30 (c) positioning a second electrode on a portion of the  
31 body;

32 (d) electrifying the second electrode; and

33 (e) measuring a signal at at least some of the elements  
34 of the multi-element probe.

35 Preferably (b) comprises positioning a second multi-  
36 element probe on a side of the breast substantially opposite

1 the multi-element probe.

2 There is further provided, in accordance with a  
3 preferred embodiment of the invention a method of impedance  
4 imaging of the breast comprising:

5 positioning a first multi-element probe, comprising a  
6 plurality of sensing elements, on one side of the breast;

7 positioning a second multi-element probe on a side of  
8 the breast substantially opposite the multi-element probe;

9 electrifying fewer than all of the plurality of  
10 sensing elements of the second multi-element probe; and

11 measuring a signal at at least some of the elements of  
12 the first multi-element probe.

13 There is further provided, in accordance with a  
14 preferred embodiment of the invention a method for guidance  
15 in the placement of an elongate element in a region of a  
16 subject comprising:

17 (a) inserting the elongate element into tissue, said  
18 element including a plurality of impedance measuring sensing  
19 elements thereon;

20 (b) measuring the impedance between the plurality of  
21 sensing elements and an electrode in contact with the  
22 subject; and

23 (c) guiding the element to a desired position having  
24 defined impedance properties in response to measurements of  
25 impedance made in (b).

26 Preferably the method also includes:

27 imaging the region of the subject including the  
28 elongate element and generating an image thereof;

29 receiving the image and the measurements of impedance  
30 made in (b) and superimposing a representation of the  
31 impedance measurements on the image of the elongate element  
32 and surrounding tissues; and

33 displaying said superimposed images.

34 In a preferred embodiment of the invention the outer  
35 surface of the elongate element is formed with a matrix of  
36 impedance measuring elements each measuring the tissue

1 impedance in a direction generally perpendicular to the  
2 element and the display indicates a guiding direction for  
3 the elongate element based on the impedance measurements.

4       There is further provided, in accordance with a  
5 preferred embodiment of the invention, a method for guidance  
6 in the placement of an elongate element in portion of a  
7 patient comprising:

8       forming a first two-dimensional impedance image of at  
9 least a part of said portion from a given direction;

10       forming second a two dimensional impedance image of at  
11 least a part of the portion using a multi-element impedance  
12 probe placed at a known angle to the plane of the first  
13 image;

14       inserting the elongate element between elements of the  
15 multi-element probe; and

16       guiding the elongate element to a point at which a  
17 biopsy is to be taken at least partially under the guidance  
18 of the first and second two dimensional images.

19       Preferably, the elongate element is inserted into the  
20 body through a hole in an array of impedance probe elements  
21 and including:

22       providing a two-dimensional impedance image based on  
23 signals received by the array;

24       guiding the elongate element based on the two-  
25 dimensional image; and

26       determining the desired depth of the elongate element  
27 based on impedance signals received from the impedance  
28 measuring elements on the elongate element.

29       There is further provided, in accordance with a  
30 preferred embodiment of the invention, a method comprising:

31       providing an impedance measurement system including a  
32 multi-element probe attached to at least one finger of an  
33 examiner; and

34       providing an indication of impedance which is generated  
35 on the basis of signals detected by said elements, whereby  
36 both a tactile and impedance indication of tissue being

1 examined are simultaneously acquired.

2 There is further provided, in accordance with a  
3 preferred embodiment of the invention, a method for  
4 improving the sensitivity of impedance imaging comprising:  
5 contacting tissue with a multi-element probe;  
6 contacting a different portion of tissue with at least  
7 one electrode;  
8 exciting the at least one electrode with a pulsed  
9 voltage;  
10 measuring signals, responsive to said pulsed voltage at  
11 at least a plurality of the elements of the probe;  
12 computing the real and imaginary parts of an admittance  
13 represented by said voltage and signals for a plurality of  
14 frequencies at a plurality of said elements; and  
15 choosing at least one frequency as a measurement  
16 frequency which gives a large difference for said measures  
17 at s elected different elements of the probe.

18 There is further provided, in accordance with a  
19 preferred embodiment of the invention, a method for  
20 identifying, in a multi-element impedance probe which forms  
21 an impedance map of tissue when placed on the surface  
22 thereof, artifacts among impedance deviations from the  
23 surroundings, the method comprising:  
24 manipulating the tissue underlying the probe while the  
25 probe remains in stationary contact with the surface of the  
26 tissue; and  
27 identifying as a non-artifact those impedance  
28 deviations which shift in the direction of the manipulation  
29 on the impedance map.

30 There is further provided, in accordance with a  
31 preferred embodiment of the invention, a method for  
32 identifying, in a multi-element impedance probe which forms  
33 an impedance map of tissue when placed on the surface  
34 thereof, artifacts among impedance deviations from the  
35 surroundings, the method comprising:  
36 moving the probe along the surface of the tissue; and

1 identifying as an artifact those impedance deviations  
2 which remain stationary or disappear in the impedance map  
3 when the probe is moved.

4 There is further provided, in accordance with a  
5 preferred embodiment of the invention, a method for  
6 identifying, in a multi-element impedance probe which forms  
7 an impedance map of tissue when placed on the surface  
8 thereof, artifacts among impedance deviations from the  
9 surroundings, the method comprising:

10 moving the probe together with the tissue; and  
11 identifying as a fixed artifact those impedance  
12 deviations which move on the impedance map, in the opposite  
13 direction from the movement of the probe and the tissue.

14 There is further provided, in accordance with a  
15 preferred embodiment of the invention, a method of  
16 displaying impedance imaging information comprising:

17 displaying at least one impedance image of a region;  
18 and

19 displaying an indication of the imaged region on a  
20 representation of the physiology of the patient.

21 Preferably the display method includes:

22 simultaneously displaying both a capacitance and a  
23 conductance map of the same region.

24 There is further provided, in accordance with a  
25 preferred embodiment of the invention, a method of  
26 displaying impedance imaging information comprising:

27 displaying a capacitance map of a region; and  
28 simultaneously displaying a conductance map of the same  
29 region.

30 There is further provided, in accordance with a  
31 preferred embodiment of the invention, a method of  
32 displaying impedance imaging information comprising:

33 computing maps of a plurality of imaging measures; and  
34 simultaneously displaying the measures.

35 There is further provided, in accordance with a  
36 preferred embodiment of the invention, a method of

1 displaying impedance information comprising:  
2       computing a plurality of maps of at least one imaging  
3 measure at a plurality of frequencies; and  
4       simultaneously displaying the maps.

5       There is further provided, in accordance with a  
6 preferred embodiment of the invention, a method of  
7 differentiating a suspected carcinoma from a suspected  
8 atypical hyperplasia comprising:

9       comparing a capacitance map of a region to a  
10 conductance map of the same region;

11       classifying a deviation from the surroundings as a  
12 suspected atypical hyperplasia if at some frequency less  
13 than 500 Hz the capacitance value is lower than that of the  
14 surroundings and the conductance value is higher than that  
15 of the surroundings; and

16       classifying a deviation from the surroundings as a  
17 suspected cancer if at some frequency less than 500 Hz both  
18 the capacitance value and the conductance value are  
19 higher than that of the surroundings.

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1                    BRIEF DESCRIPTION OF THE DRAWINGS

2            The invention will be more fully understood and  
3 appreciated from the following detailed description, taken  
4 in conjunction with the drawings in which:

5            Fig. 1 is an overall view of an impedance mapping  
6 system especially suitable for breast impedance mapping in  
7 accordance with a preferred embodiment of the invention;

8            Fig. 2 is a perspective view of an imaging head  
9 suitable for breast impedance mapping in accordance with a  
10 preferred embodiment of the invention;

11           Figs. 3A and 3B show partially expanded views of two  
12 preferred probe head configurations suitable for use in the  
13 imaging head of Fig. 2;

14           Fig. 4 is a top view of a portion of a multi-element  
15 probe in accordance with a preferred embodiment of the  
16 invention;

17           Fig. 5A is a partial, partially expanded cross-  
18 sectional side view of the probe of Fig. 4 along lines V-V,  
19 suitable for the probe head configuration of Fig. 3B;

20           Fig. 5B is a partially expanded cross-sectional side  
21 view of an alternative probe in accordance with a preferred  
22 embodiment of the invention;

23           Fig. 5C shows an alternative embodiment of a multi-  
24 element probe, in accordance with a preferred embodiment of  
25 the invention;

26           Fig. 6A is a perspective view of a hand held probe in  
27 accordance with a preferred embodiment of the invention;

28           Fig. 6B shows a partially expanded bottom view of the  
29 probe of Fig. 6A, in accordance with a preferred embodiment  
30 of the invention;

31           Fig. 7A is a perspective view of a fingertip probe in  
32 accordance with a preferred embodiment of the invention;

33           Fig. 7B shows a conformal multi-element probe;

34           Fig. 8 shows an intra-operative probe used determining  
35 the position of an abnormality in accordance with a  
36 preferred embodiment of the invention;

1        Fig. 9 shows a laparoscopic probe in accordance with a  
2 preferred embodiment of the invention;

3        Fig. 10 shows a biopsy needle in accordance with a  
4 preferred embodiment of the invention;

5        Fig. 11A illustrates a method of using the biopsy  
6 needle of Fig. 10, in accordance with a preferred embodiment  
7 of the invention;

8        Fig. 11B illustrates a portion of a display used in  
9 conjunction with the method of Fig. 11A;

10       Fig. 11C shows a biopsy guiding system in accordance  
11 with a preferred embodiment of the invention;

12       Fig. 11D shows a frontal biopsy guiding system in  
13 accordance with a preferred embodiment of the invention;

14       Fig. 11E shows a lateral biopsy guiding system in  
15 accordance with a preferred embodiment of the invention;

16       Fig. 12 shows, very schematically, the inter-operative  
17 probe of Fig. 8 combined with a video camera use to more  
18 effectively correlate an impedance measurement with  
19 placement of the probe.

20       Fig. 13 illustrates a laparoscopic probe according to  
21 the invention used in conjunction with a fiber-optic  
22 illuminator-imager;

23       Fig. 14 illustrates a display, according to a preferred  
24 embodiment of the invention showing both capacitive and  
25 conductance images illustrative of atypical hyperplasia;

26       Fig. 15 illustrates a display, according to a preferred  
27 embodiment of the invention showing both capacitive and  
28 conductance images illustrative of a carcinoma; and

29       Fig. 16 illustrates a method useful for verifying a  
30 detected local impedance deviation as being non-artifactual  
31 and for estimating the deviation;

32       Figs. 17A and 17B are a block diagram of circuitry  
33 suitable for impedance mapping in accordance with a  
34 preferred embodiment of the invention.

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1           DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

2           Reference is made to Figs. 1 and 2 which illustrate an  
3 impedance mapping device 10 suitable for mapping the  
4 impedance of a breast.

5           Mapping device 10 includes an imaging head 12, which is  
6 described below, which holds the breast and provides contact  
7 therewith for providing electrical excitation signals  
8 thereto and for receiving resultant electrical signals  
9 therefrom. Signals to and from the head are generated and  
10 received by a computer/controller 14 which produces  
11 impedance maps of the breast under test for display on a  
12 monitor 16. The impedance maps may be stored in  
13 computer/controller 14 for later viewing or processing or  
14 hard copies may be provided by a hard copy device 18 which  
15 may be a laser printer, video printer, Polaroid or film  
16 imager or multi-imager.

17           The entire mapping device 10 may be conveniently  
18 mounted on a dolly 20 to facilitate placement of the imaging  
19 head with respect to the patient.

20           Fig. 1 also shows a hand held probe 100, described in  
21 more detail below, and a reference probe 13.

22           Fig. 2 shows imaging head 12 in more detail. Head 12  
23 comprises a movable lower plate probe 22 and a stationary  
24 upper plate probe 24 which is mounted on a pair of rails 26  
25 to allow the distance between plate probes 22 and 24 to be  
26 varied.

27           Movement of plate probe 22 along rails 26 may be  
28 achieved either by a motor (not shown) including suitable  
29 protection against over-pressure as is traditional in X-ray  
30 breast imaging, or by hand.

31           Either or both of plate probes 22 and 24 are provided  
32 with multi-element probes 28 and 30 respectively, which are  
33 described more fully below, which electrically contact the  
34 breast with a plurality of sensing elements to optionally  
35 provide electrical excitation to the breast and to measure  
36 signals generated in response to the provided signals.

1 Alternatively, electrical excitation to the breast is  
2 provided by reference probe 13 which is placed on the arm,  
3 shoulder or back of the patient, or other portion of the  
4 patient.

5 In practice, a breast is inserted between probes 28 and  
6 30 and plate probe 24 is lowered to compress the breast  
7 between the probes. This compression reduces the distance  
8 between the probes and provides better contact between the  
9 sensing elements and the skin of the breast. Although  
10 compression of the breast is desirable, the degree of  
11 compression required for impedance imaging is much lower  
12 than for X-Ray mammography, and the mapping technique of the  
13 present invention is typically not painful.

14 Alternatively or additionally, the probes are curved to  
15 conform with the surface of the breast.

16 Head 12 is provided with a a pivot (not shown) to allow  
17 for arbitrary rotation of the head about one or more of its  
18 axes. This allows for both medio-lateral and cranio-caudal  
19 maps of the breast to be acquired, at any angular  
20 orientation about the breast. Preferably, head 12 may be  
21 tilted so that the surfaces of plate probes 22 and 24 are  
22 oriented with a substantial vertical component so that  
23 gravity assists the entry of the breast into the space  
24 between the maximum extent and to keep it from inadvertently  
25 falling out. This is especially useful when the patient  
26 leans over the plates so that her breasts are positioned  
27 downwardly between the plate probes.

28 Furthermore, in a preferred embodiment of the  
29 invention, one or both of probes 28 and 30 may be rotated  
30 about an axis at one end thereof, by a rotation mechanism 27  
31 on their associated plate probes 22 or 24, such as is shown  
32 in Fig. 2 for probe 28. Additionally or alternatively,  
33 probes 28 and/or 30 may be slidable, as for example along  
34 members 31.

35 Such additional sliding and rotating flexibility is  
36 useful for providing more intimate skin contact of the

1 probes with the breast, which has a generally conical shape.  
2 Furthermore, such flexibility allows for better imaging of  
3 the areas of the breast near the chest wall or the rib cage,  
4 which are extremely difficult to image in x-ray mammography.

5 Figs. 3A and 3B show partially expanded views of two  
6 probe head configurations suitable for use in the imaging  
7 head of Fig. 2, in accordance with preferred embodiments of  
8 the invention.

9 In the embodiment of Fig. 3A, a preferably removable  
10 multi-element probe 62, which is described below in more  
11 detail, is attached to a probe head base 50 via a pair of  
12 mating multi-pin connectors 51 and 52. A cable 53 couples  
13 connector 52 to computer 14. When multi-element probe 62 is  
14 inserted into base 50 (that is to say, when connector 51 is  
15 fully inserted into connector 52), the relatively stiff  
16 bottom of probe 62 rests on ledges 54 formed in the base,  
17 such that the surface 55 of the base and the surface of  
18 element 62 are preferably substantially coplanar.

19 In the embodiment of Fig. 3B, a series of contacts 82  
20 are formed on base 50 and a disposable multi-element probe  
21 62' is attached to the contacts as described below with  
22 reference to Fig. 5A and 5B. Cable 53 couples the contacts  
23 to computer 14.

24 Figs. 4, 5A and 5B show top and side views of a portion  
25 of multi-element probe 62' and contacts 74, while Figs. 5A  
26 and 5B show a partially expanded cross-sectional side view  
27 of probe 62' along lines V-V. While the embodiment shown in  
28 Figs. 4, 5A and 5B is especially suitable for the probe head  
29 configuration of Fig. 3B, much of the structure shown in  
30 these figures 5 is common to multi-element probes used in  
31 other configurations described herein.

32 As shown in Figs. 4, 5A and 5B, disposable multi-  
33 element probe 62' preferably incorporates a plurality of  
34 sensing elements 64, separated by separator or divider  
35 elements 66.

36 As shown more clearly in Figs. 5A and 5B, sensing

1 elements 64, comprise a bio-compatible conductive material  
2 (for example Neptrode E0751 or Neptrode E0962 Hydrogel  
3 distributed by Cambrex Hydrogels, Harriman, NY) such as is  
4 sometimes used for ECG probes in a well 70 formed by a  
5 first, front, side of a mylar or other flexible, non-  
6 conducting substrate 68, such as a thin mylar sheet and the  
7 divider elements 66. A suitable thickness for the mylar  
8 sheet is approximately 0.2 mm for probe 62'. The substrate  
9 is preferably pierced in the center of each well. The hole  
10 resulting from the piercing is filled with a conducting  
11 material which is also present on the bottom of well 70 and  
12 on a second, back, side of substrate 68 to form a pair of  
13 electrical contacts 72 and 74 on either side of the  
14 substrate and an electrically conducting feed-through 76  
15 between the pair of contacts. As shown, a separate contact  
16 pair and feed-through is provided for each sensing element.

17 Alternatively, the substrate may be formed of any  
18 suitable inert material including plastics such as  
19 polyethylene, polypropylene, PVC, etc.

20 Wells 70 may be formed in a number of ways. One method  
21 of forming the wells is to punch an array of square holes in  
22 a sheet of plastic, such as polypropylene, which is about  
23 0.2-1mm thick. This results in a sheet containing only the  
24 divider elements. This sheet is bonded to substrate 68 which  
25 has been pre-pierced and in which the contacts and feed-  
26 throughs have been formed. Another method of forming the  
27 wells is to emboss a substrate containing the contacts and  
28 feed-throughs to form divider elements in the form of ridges  
29 which protrude from the substrate as shown in Fig. 5B. Yet  
30 another method of producing the wells is by printing the  
31 well walls using latex based ink or other bio-compatible  
32 material having a suitable firmness and flexibility. Another  
33 method of production is by injection molding of the  
34 substrate together with the divider elements. And yet  
35 another method of producing the wells is by laminating to  
36 the substrate a preformed grid made by die cutting the array

1 of divider elements in a sheet of plastic, injection  
2 molding, or other means.

3 The conductors and feed-throughs may be of any  
4 conductive material which will provide reliable feed-through  
5 plating of the holes. One method of manufacturing the  
6 contacts and holes is by screen printing of the contacts on  
7 both sides of the substrate. If conductive paste having a  
8 suitable viscosity is used, the paste will fill the hole and  
9 form a reliable contact between contacts 72 and 74. Although  
10 many conductive materials can be used, non-polarizing  
11 conductors, such as silver/silver chloride are preferred. A  
12 conductive paste suitable for silk screening the conductors  
13 onto the substrate is Pad Printable Electrically conductive  
14 Ink No. 113-37 manufactured and sold by Creative Materials  
15 Inc., Tyngsboro, MA.

16 In general contacts 72 and 74 are only 10-200 microns  
17 thick and wells 70 are generally filled with conductive  
18 viscous gel material or hydrogel material to within about  
19 0.2 mm of the top of the dividing elements. In general, if  
20 low separators are used, the hydrogel may be omitted.  
21 However, in the preferred embodiment of the invention, the  
22 wells are at least partially filled by hydrogel or a similar  
23 material.

24 Hydrogel is available in both UV cured and heat cured  
25 compositions. In either case a measured amount of uncured  
26 semi-liquid hydrogel is introduced into each well and the  
27 hydrogel is cured. Alternatively, the wells are filled with  
28 the uncured material and a squeegee which is pressed against  
29 the top of the divider elements with a predetermined force  
30 is moved across the top of the divider elements. This will  
31 result in the desired gap between the top of the hydrogel  
32 and the top of the wells.

33 In an alternative embodiment of the invention, the  
34 hydrogel material is replaced by a sponge material or  
35 similar supportive matrix impregnated with conductive  
36 viscous gel or the well is simply filled with the conductive

1 gel to the desired height.

2       During use of the probe, the probe is urged against the  
3 skin which is forced into the wells and contacts the  
4 hydrogel or alternative conductive material. Optionally, a  
5 somewhat viscous conductive gel, such as Lectron II  
6 Conductivity Gel (Pharmaceutical Innovations, Inc. Newark,  
7 NJ), may be used to improve contact with the skin. In this  
8 case, the dividing elements will reduce the conduction  
9 between the cells such that the substantial independence of  
10 the individual measurements is maintained. Alternatively,  
11 the conductive gel may be packaged together with the probe,  
12 with the conductive gel filling the space between the top of  
13 the hydrogel and the top of the wells. The use of a  
14 conductive gel is preferred since this allows for sliding  
15 movement of the probe and its easy positioning while it is  
16 urged against the skin. The separators substantially prevent  
17 the conductive gel from creating a low conductance path  
18 between adjoining sensing elements and also keep the  
19 hydrogel elements from touching each other when the probe is  
20 applied to the skin with some pressure.

21       In a further preferred embodiment of the invention, the  
22 sensing elements are formed of a conductive foam or sponge  
23 material such as silicone rubber or other conductive rubber  
24 or other elastomer impregnated with silver or other  
25 conductive material, as shown in Fig. 5C. Fig. 5C shows the  
26 sensing elements without walls 66. Elements which protrude  
27 from the substrate as shown in Fig. 5C may achieve  
28 substantial electrical isolation from one another by spacing  
29 them far enough apart so that do not contact each other in  
30 use or by coating their lateral surfaces with insulating  
31 material such as polyethylene or other soft non-conductive  
32 plastic or rubber.

33       For relatively short rigid or compressible elements, it  
34 has been found that reducing the size of the sensing  
35 elements such that no more than 70% (and preferably no more  
36 than 50%) of the area of the array is covered is sufficient

1 to reduce the "cross-talk" between adjoining elements to an  
2 acceptable level.

3 If sufficiently good isolation is achieved between  
4 probe elements by their spacing alone, then foam or other  
5 elements without hydrogel and without walls 66 may be  
6 provided. Sensing elements such as those shown in Fig. 5C  
7 conform and mate to uneven surfaces when pressed against  
8 tissue.

9 Multi-element probe 62', which is preferably used for  
10 only one patient and then discarded, is preferably removably  
11 attached to a probe holder which preferably comprises a  
12 printed circuit board 80 having a plurality of contacts 82  
13 corresponding to the contacts 74 on the back of the  
14 substrate, each PC board contact 82 being electrically  
15 connected to a corresponding contact 74 on the substrate.  
16 To facilitate alignment of the matching contacts, an  
17 alignment guide 90 is preferably provided on or adjacent to  
18 PC board 80 (Fig. 4). This guide may consist of a series of  
19 guide marks or may consist of a raised edge forming a well  
20 into or onto which the substrate is inserted. Conductors  
21 within PC board 80 connect each of the contacts to one of  
22 the pins of connector 51, which is preferably mounted on PC  
23 board 80.

24 Alternatively and preferably, as described below with  
25 respect to Fig. 6B, the guide may consist of two or more  
26 pins located on or near PC board 80, which fit into matching  
27 holes in probe 62'.

28 Alternatively as shown in Fig. 5B, the back side of the  
29 embossing of substrate 68 is used as the guide for one or  
30 more protruding elements 83 which are preferably mounted on  
31 PC board 80. Preferably a plurality of protruding elements  
32 are provided to give good alignment of the substrate with  
33 the PC board. The elements may run along the periphery of  
34 the probe and form a frame-like structure as shown in Fig.  
35 5B or may run between the elements or may take the form of x  
36 shaped protuberances which match the shape of the embossing

1 at the corners of the wells.

2 Protruding elements 83 may be formed of polycarbonate,  
3 acetate, PVC or other common inert plastic, or of a  
4 noncorrosive metal such as stainless steel.

5 A wire 84 is connected to each PC contact 82 and is  
6 also connected to apparatus which provides voltages to  
7 and/or measures voltages and/or impedances at the individual  
8 sensing elements 64, as described below.

9 In a preferred embodiment of the invention, conductive  
10 adhesive spots 86 preferably printed onto the back of the  
11 substrate are used to electrically and mechanically connect  
12 contacts 74 with their respective contacts 82. Preferably a  
13 conductive adhesive such as Pressure Sensitive Conductive  
14 Adhesive Model 102-32 (Creative Materials Inc.) is used.  
15 Alternatively, the adhesive used for printing the  
16 contacts/feed-throughs is a conducting adhesive and adhesive  
17 spots 86 may be omitted. Alternatively, pins, which protrude  
18 from the surface of PC board 80 and are connected to wires  
19 84 pierce the substrate (which may be pre-bored) and contact  
20 the gel or hydrogel in the wells. A pin extending from the  
21 substrate may also be inserted into a matching socket in the  
22 PC board to form the electrical connection between the  
23 sensing element and the PC board. Alternatively, the entire  
24 back side of the substrate can be adhered to the printed  
25 circuit board surface using an anisotropically conductive  
26 thin film adhesive which has a high conductivity between  
27 contacts 74 and 82 and which has a low conductivity  
28 resulting in preferably many times higher resistance between  
29 adjoining contacts than between matching contacts, in  
30 practice at least one hundred times different. An example of  
31 such adhesive is tape NO. 3707 by MMM Corporation,  
32 Minneapolis MN. However, due to the difficulty of applying  
33 such material without trapped air bubbles, it may be  
34 preferably to apply adhesive only to the contacts  
35 themselves. In practice a release liner of polyethylene,  
36 mylar or paper with a non-stick surface on one side is

1 provided on the lower side of the adhesive sheet. This liner  
2 protects the adhesive layer prior to connection of the  
3 disposable multi-element probe to the probe holder and is  
4 removed prior to the connection of the probe to the holder.

5 Preferably, the impedance between contacts 82 and skin  
6 side of the conducting material in the wells should be less  
7 than 100 ohms at 1 kHz and less than 400 ohms at 10 Hz.

8 Impedance between any pair of contacts 82, with the  
9 multi-element probe mounted should preferably be greater  
10 than 10 kohm at 1 kHz or 100 kohm at 10 Hz.

11 Another suitable material for producing substrates is  
12 TYVEX (DuPont) substrate which is made from a tough woven  
13 polyolefin material available in various thicknesses and  
14 porosities. If such material having a suitable porosity is  
15 used, contacts 72 and 74 and feed-through 76 can be formed  
16 by a single printing operation with conductive ink on one  
17 side of the TYVEX sheet. Due to the porosity of the TYVEX,  
18 the ink will penetrate to the other side of the TYVEX and  
19 form both contacts and feed-through in one operation.

20 For probe 62 in the embodiment of Fig. 3A, substrate  
21 68 is replaced by a relatively rigid PC board which includes  
22 conducting wires to attach each of electrical contacts 72 to  
23 one of the pins of connector 51 (Fig. 3A) and the rest of  
24 the connecting structure of Fig. 5A may be omitted. It  
25 should be noted that the choice of using the structure of  
26 Figs. 3A or 3B (i.e., probes 62 or 62') is an economic one  
27 depending on the cost of manufacture of the probes. While  
28 probe 62 is structurally simpler, the disposable portion of  
29 probe 62' is believed to be less expensive to manufacture in  
30 large quantities. Since it is envisioned that the probes  
31 will be used in large quantities and will preferably not be  
32 reused, one or the other may be preferable.

33 The other side of the probe is also protected by a  
34 cover plate 88 (Figs. 5A and 5B) which is attached using any  
35 bio-compatible adhesive to the outer edges of dividers 66  
36 (Fig. 5A) and/or to the hydrogel, which is preferably

1 moderately tacky. In one preferred embodiment of the  
2 invention, the inner surface of the cover plate 88 is  
3 provided with an electrically conductive layer so that the  
4 impedance of each sensing element from the outer surface of  
5 the hydrogel (or conductive gel) to contact 82, can be  
6 measured using an external source. In addition, if a known  
7 impedance is connected between the conductive layer and a  
8 reference point or a source of voltage, the sensing elements  
9 can be tested in a measurement mode similar to that in which  
10 they will finally be used.

11 Alternatively, a film RC circuit or circuits may be  
12 printed on the inner surface of plate 88 to simulate an  
13 actual impedance imaging situation. Alternatively, plate 88  
14 may be provided with contacts at each sensing location, and  
15 circuitry which may simulate a plurality of actual impedance  
16 imaging situations. Such circuitry may include external or  
17 integral logic such as programmable logic arrays and may be  
18 configurable using an external computer interface. The  
19 simulation may provide a distinct RC circuit for each  
20 sensing element or may provide a sequence of different  
21 circuits to each sensing element to simulate the actual  
22 range of measurements to be performed using the probe.

23 Fig. 5B shows a preferred embodiment of cover sheet 88  
24 (indicated on the drawing as 88') and its mode of attachment  
25 to both the multi-element sensor and the PC board. In this  
26 embodiment a multi-element probe 62" is optionally further  
27 attached to PC board 80 by an adhesive frame 210 which may  
28 be conductive or non-conductive, and which assists in  
29 preventing entry of water or gel under sensor 62". Sensor  
30 62" is preferably further aligned to PC board 80 by one or  
31 more holes 222 with one or more pins 204, which are  
32 permanently attached to PC board 80 or to a surface adjacent  
33 to PC board 80. While pin 204 is shown as being round, using  
34 rectangular, triangular, hexagonal pyramidal or other  
35 shapes provides additional alignment of the sensor. In  
36 general the upper portion of the pin should be curved for

1 improved electrical contact as described below.

2       The upper exposed surface of pin 204 is conductive,  
3 preferably curved and is preferably connected to a signal  
4 reference source by a conductor 202 in PC board 80. Cover  
5 sheet 88' is made of a single integral sheet of easily  
6 deformable polyethylene, Mylar or other suitable plastic.  
7 Cover sheet 88' is preferably removably attached to the  
8 upper side of multi-element probe 62" by a continuous frame  
9 of adhesive 225, which need not be conductive, but which  
10 seals around a lip where cover 88' contacts probe 62" to  
11 protect the quality and sterility of array 230 and to  
12 maintain the moisture content of any medium filling wells  
13 70. Cover 88' is coated on the side facing probe 62" with a  
14 conductive layer 231, such as any of the various metallic  
15 coatings, for example, aluminum or the thin film coating  
16 described above.

17       Cover 88' is preferably formed after conductive  
18 coating, by embossing, vacuforming or other means, to have  
19 depressions 233 in the cover located over corresponding  
20 wells 70. The depressions are approximately centered on the  
21 center of the wells and held a small distance " $\delta 1$ " above  
22 the surface of the hydrogel or gel, by means of relatively  
23 high sidewalls 226 which are formed at the same time as  
24 depressions 233. Furthermore, the surface of cover 88'  
25 preferably has a concave shape to match the rounded  
26 conductive contact surface of pin 204, from which it is  
27 held at a distance " $\delta 2$ ". Distances  $\delta 1$  and  $\delta 2$  are selected to  
28 minimize unintended physical contact between the conductive  
29 inner surface of the cover, the contacts in the wells and  
30 pin 204, for example, during storage and handling prior to  
31 use, which might cause corrosion over time due to  
32 electrochemical processes.

33       Distances  $\delta 1$  and  $\delta 2$  are also preferably selected so  
34 that application of a nominal force (preferably about one  
35 kilogram) against a flat outer surface 232 of cover 88',  
36 such as by a weighted flat plate, will establish contact

1 between the inner coating 231 and the upper surface of pin  
2 204 and with the sensing elements or the gel in the wells.

3 By establishing this contact, the conductive inner  
4 surface 231 is connected, on the one hand to signals source  
5 contact 202 and with each sensing element. If the coating is  
6 a conductor, the sensing elements are all excited by the  
7 signal on line 202; if it is a thin film circuit, the  
8 contact is via the thin film circuit. In either event, if  
9 line 202 is excited by a signal, the signal will be  
10 transmitted to each of the sensing elements, either  
11 directly, or via a known impedance.

12 In either case, the multi-element array can be tested  
13 by the system and any residual impedance noted and corrected  
14 when the probe is used for imaging. If the residual  
15 impedance of a given sensing element is out of a  
16 predetermined specification, or is too large to be  
17 compensated for, the multi-element probe will be rejected.  
18 Furthermore, the computer may be so configured that imaging  
19 may only take place after determination of the contact  
20 impedance of the sensing elements or at least of  
21 verification that the probe impedances are within a  
22 predetermined specification.

23 While pin 204 is shown as being higher than the top of  
24 the wells, the pin may be at the same height as the wells,  
25 or even below the wells with the cover being shaped to  
26 provide a suitable distance "62" as described above.

27 In an alternative embodiment of the invention, the  
28 contact surface corresponding to pin 204 is printed on or  
29 attached to the surface holding the sensing elements, with  
30 contact to the PC board being via a through contact in  
31 substrate 68, as for the sensing elements.

32 In yet another embodiment of the invention, the  
33 conductive contact surface associated with pin 204 is on the  
34 surface holding the sensing elements adjacent to pin 204.  
35 Pin 204 supports this surface and contacts the contact  
36 surface via one, or preferably a plurality of through

1 contacts. Pin 204 is designed to match the contour of the  
2 contact surface and preferably, by such matching, to provide  
3 additional alignment of the probe on the PC board.

4 To avoid drying out of the Gel or other potential  
5 hazards of limited shelf life, the quality of any of the  
6 aforementioned versions of the disposable electrode arrays  
7 can be assured by incorporating an identification code,  
8 preferably including manufacturer and serial number  
9 information and date of manufacture. In a preferred  
10 embodiment, the information is coded in a bar code printed  
11 on each disposable probe, which is packaged together with at  
12 least one other such probe (typically 5-50 probes) in the  
13 same packet, which also has the same bar code. A bar code  
14 reader, interfaced with the system computer, reads the  
15 manufacturing information on the packet and each probe,  
16 checking for date and compliance and permitting recording  
17 only for a number of patients equal to the number of probes  
18 in the packet.

19 In a preferred embodiment of the invention a bar code  
20 may be placed on the individual disposable electrode arrays  
21 which can be read by a bar code reader installed in or under  
22 the PC board, for example near reference numeral 83 of Fig.  
23 5B.

24 While the invention has been described in conjunction  
25 with the preferred embodiment thereof, namely a generally  
26 flat, somewhat flexible structure, suitable for general use  
27 and for breast screening, other shapes, such as concave  
28 structures (e.g., brassiere cups) or the like may be  
29 preferable, and in general the shape and configuration of  
30 the detectors will depend on the actual area of the body to  
31 be measured. For example cylindrical arrays can be useful in  
32 certain situations, for example in intra-rectal examinations  
33 of the prostate or colon or inside vessels. In this context,  
34 a probe according to the invention is also useful for  
35 measurements inside the body, for example gynecological  
36 measurements or measurements in the mouth, where the probe

1 is inserted into a body cavity and contacts the lining of  
2 the cavity, and probes having shapes which correspond either  
3 flexibly or rigidly to the surface being measured can be  
4 used. For example, a multi-element probe in accordance with  
5 the invention may be incorporated into or attached to a  
6 laparoscopic or endoscopic probe.

7 Furthermore, sterilized probes can be used in invasive  
8 procedures in which the probe is placed against tissue  
9 exposed by incision. In this context, the term "skin" or  
10 "tissue surface" as used herein includes such cavity lining  
11 or exposed tissue surface.

12 In a preferred embodiment of the invention, PC board 80  
13 and as many elements as possible of probe 62' (or the board  
14 of probe 62) are made of transparent or translucent  
15 material, so as to provide at least some visibility of the  
16 underlying tissue during placement of probe 62. Those  
17 elements of the probe and conductors in the PC board, to the  
18 extent that they are opaque should be made as small as  
19 practical to provide the largest possible view to a  
20 technician or clinician to aid in placement of the probe.  
21 Furthermore, probe 62 is slidably displaceable when used  
22 with the above-mentioned conductive gel to permit moderate  
23 lateral adjustment of the probe position, to aid in  
24 placement, to ensure good contact between each element and  
25 the tissue surface to be measured, and to enable the user to  
26 rapidly verify whether detected abnormalities are artifacts  
27 due to poor contact or are genuine objects, since artifacts  
28 remain stationary or disappear entirely when the probe is  
29 moved while genuine objects just move in a direction  
30 opposite to the direction of movement of the probe.

31 The general shape and size of the multi-element probe  
32 and the size of the conductive sensing elements will depend  
33 on the size of the area to be measured and on the desired  
34 resolution of the measurement. Probe matrix sizes of greater  
35 than 64 x 64 elements are envisioned for viewing large areas  
36 and probes which are as small as 2 x 8 elements can be

1 useful for measuring small areas. Element size is preferably  
2 between 2 mm square and 8 mm square; however, larger sizes  
3 and especially smaller sizes can be useful under certain  
4 circumstances. For the breast probe 62 described above, 24 x  
5 32 to 32 x 40 elements appear to be preferred matrix sizes.

6 Fig. 6A shows a perspective view of a hand held probe  
7 100 in accordance with a preferred embodiment of the  
8 invention. Probe 100 preferably comprises two probe heads, a  
9 larger head 102 and a zoom sensor head 104. A handle 106  
10 connects the sensor heads, houses switching electronics and  
11 provides means for holding and positioning the probes.  
12 Handle 106 also optionally incorporates a digital pointing  
13 device 105 such as a trackball, pressure sensitive button or  
14 other such joystick device. Incorporation of a pointing  
15 device on the probe enables the operator to control the  
16 system and input positional information while keeping both  
17 hands on either the probe or patient. As described below,  
18 the digital pointing device can be used to indicate the  
19 position on the patient's body at which the image is taken.

20 Fig. 6B shows a partially expanded bottom view of probe  
21 100 of Fig. 6A, in accordance with a preferred embodiment of  
22 the invention. Where applicable, like parts of the probes  
23 throughout this disclosure are similarly numbered. Starting  
24 from the bottom of Fig. 6B, the top half of a housing 108A  
25 has a well 110 formed therein. A clear plastic window 112 is  
26 attached to the edge of well 110, and a printed circuit on a  
27 relatively transparent substrate, such as Kapton, designated  
28 by reference 80' (to show its similarity to the  
29 corresponding unprimed element of Fig. 5) is placed on  
30 window 112. A flexible print cable 114 connects the contacts  
31 on printed circuit 62' to acquisition electronics 116. A  
32 cable 118 connects the acquisition electronics to the  
33 computer. A second similarly constructed, but much smaller  
34 zoom sensor probe head is attached to the other end of probe  
35 100. Either of the larger or smaller heads may be used for  
36 imaging.

1       A lower half of housing 108B, encloses electronics 116  
2   and print 80', whose face containing a series of contacts  
3   82', is available through an opening 120 formed in the lower  
4   housing half 108B. A mounting frame 122 having two alignment  
5   pins 124 holds print 80' in place. Mounting and connecting  
6   screws or other means have been omitted for simplification.

7       A disposable multi-element probe 62', similar to that  
8   of Fig. 5 is preferably mounted on the mounting frame to  
9   complete the probe.

10      Fig. 7A is a perspective view of a fingertip probe 130  
11   in accordance with a preferred embodiment of the invention  
12   as mounted on the finger 132 of a user. Probe 130 may be  
13   separate from or an integral part of a disposable glove,  
14   such as those normally used for internal examinations or  
15   external palpation. The fingertip probe is especially useful  
16   for localizing malignant tumors or investigating palpable  
17   masses during surgery or during internal examinations. For  
18   example, during removal of a tumor, it is sometimes  
19   difficult to determine the exact location or extent of a  
20   tumor. With the local impedance map provided by the  
21   fingertip probe 130 and the simultaneous tactile information  
22   about the tissue contacted by the probe, the tumor can be  
23   located and its extent determined during surgery. In a like  
24   fashion, palpable lumps detected during physical breast (or  
25   other) examination can be routinely checked for impedance  
26   abnormality.

27      Fig. 7B shows a flexible probe array 140 which is shown  
28   as conforming to a breast being imaged. Probe array 140  
29   comprises a plurality of sensing elements 141 which contact  
30   the tissue surface which are formed on a flexible substrate.  
31   Also formed on the flexible substrate are a plurality of  
32   printed conductors 142 which electrically connect the  
33   individual sensing elements 141 to conductive pads on the  
34   edge of the substrate. A cable connector 144 and cable 145  
35   provide the final connection link from the sensing elements  
36   to a measurement apparatus. Alternatively, the flexible

1 array may take a concave or convex shape such as a cup  
2 (similar in shape to a bra cup) which fits over and contacts  
3 the breast.

4 The flexible substrate is made of any thin inert  
5 flexible plastic or rubber, such as those mentioned above  
6 with respect to Fig. 5A. Array 140 is sufficiently pliant  
7 that, with the assistance of viscous gel or conductive  
8 adhesive, the sensor pads are held in intimate contact with  
9 the skin or other surface, conforming to its shape.

10 Fig. 8 shows an intra-operative paddle type probe 140  
11 used, in a similar manner as probe 130, for determining the  
12 position of an abnormality in accordance with a preferred  
13 embodiment of the invention. This probe generally includes  
14 an integral sensing array 143 on one side of the paddle.  
15 Preferably, the paddle is made of substantially transparent  
16 material so that the physical position of the array may be  
17 determined and compared with the impedance map.

18 Fig. 9 shows a laparoscopic probe 150 in accordance  
19 with a preferred embodiment of the invention. Probe 150 may  
20 have a disposable sensing array 152 mounted on its side or  
21 the sensing array may be integral with probe 150, which is  
22 disposable or sterilizable.

23 Multi-element probes, such as those shown in Figs. 7, 8  
24 and 9, are preferably disposable or sterilizable as they are  
25 generally are used inside the patients body in the presence  
26 of body fluids. In such situations, there is generally no  
27 need or desire for a conductive gel in addition to the  
28 probes themselves. Generally, printed sensing elements, such  
29 as those printed with silver-silver chloride ink, or sensing  
30 elements formed of conductive silicone, hydrogel or of a  
31 conductive sponge may be used. While in general it is  
32 desirable that the sensing elements on these multi-element  
33 probes be separated by physical separators 66 (as shown in  
34 Fig. 5), under some circumstances the physical distance  
35 between the elements is sufficient and the separators may be  
36 omitted.

1       When performing a needle biopsy, a physician generally  
2       relies on a number of indicators to guide the needle to the  
3       suspect region of the body. These may include tactile feel,  
4       X-Ray or ultrasound studies or other external indicators.  
5       While such indicators generally give a reasonable  
6       probability that the needle will, in fact take a sample from  
7       the correct place in the body, many clinicians do not rely  
8       on needle biopsies because they may miss the tumor.

9       Fig. 10 shows a biopsy needle 154, in accordance with a  
10      preferred embodiment of the invention, which is used to  
11      improve the accuracy of placement of the needle. Biopsy  
12      needle 154 includes a series of sensing elements 156 spaced  
13      along the length of the probe. Leads (not shown) from each  
14      of these elements bring signals from the elements to a  
15      detection and computing system such as that described below.  
16      Elements 156 may be continuous around the circumference, in  
17      which case they indicate which portion of the needle is  
18      within the tumor to be biopsied. Alternatively,  
19      the electrodes may be circumferentially segmented (a lead  
20      being provided for each segment) so that information as to  
21      the direction of the tumor from the needle may be derived  
22      when the needle is not within the tumor. Such an impedance  
23      sensing biopsy needle can be used, under guidance by  
24      palpation, ultrasound, x-ray mammography or other image from  
25      other image modalities (preferably including impedance  
26      imaging as described herein), taken during the biopsy or  
27      prior to the biopsy to improve the accuracy of placement of  
28      the needle. In particular, the impedance image from the  
29      needle may be combined with the other images in a display.  
30      While this aspect of the invention has been described using  
31      a biopsy needle, this aspect of the invention is also  
32      applicable to positioning of any elongate object such as an  
33      other needle (such as a localizing needle), an endoscopic  
34      probe or a catheter.

35      Returning now to Figs. 1-3 and referring additionally  
36      to Figs. 11-14, a number of applications of multi-element

1 probes are shown. It should be understood that, while some  
2 of these applications may require probes in accordance with  
3 the invention, others of the applications may also be  
4 performed using other types of impedance probes.

5       Fig. 11A shows the use of the biopsy needle in Fig. 10  
6 together with an optional ultrasound imaging head in  
7 performing a biopsy. A breast 160 having a suspected cyst or  
8 tumor 162 is to be biopsied by needle 154. An ultrasound  
9 head 164 images the breast and the ultrasound image, after  
10 processing by an ultrasound processor 166 of standard design  
11 is shown on a video display 168. Of course, the ultrasound  
12 image will show the biopsy needle. The impedance readings  
13 from probe 154 are processed by an impedance processor 170  
14 and are overlaid on the ultrasound image of the biopsy  
15 needle in the display by a video display processor 172.

16       In one display mode, the portions, as shown in Fig. 11B  
17 of the needle which are within the tumor or cyst and which  
18 measure a different impedance from those outside the tumor,  
19 will be shown in a distinctive color to indicate the portion  
20 of the needle within the tumor or cyst. In a second display  
21 mode, the impedance measured will be indicated by a range of  
22 colors. In yet a third embodiment of the invention, in which  
23 circumferentially segmented sensing elements are employed,  
24 the impedance processor will calculate radial direction of  
25 the tumor from the needle and will display this information,  
26 for example, in the form of an arrow on the display.

27       The image sensing biopsy needle can also be used with  
28 one or more imaging arrays (28, 30) such as those shown in  
29 Fig. 6 or Fig. 3B to impedance image the region to be  
30 biopsied during the biopsy procedure. Alternatively, at  
31 least one of the arrays can be an imaging array of the non-  
32 impedance type. In one preferred embodiment, shown in Fig.  
33 11C, the needle is inserted through an aperture (or one of a  
34 plurality of apertures) 174 in a multi-element probe which  
35 is imaging the region. The region may, optionally, be  
36 simultaneously viewed from a different angle (for example at

1 90° from the probe with the aperture) with an other  
2 impedance imaging probe. In the case that both arrays 28 and  
3 30 are impedance imaging arrays, the biopsy needle or other  
4 elongate object can either have impedance sensing or not,  
5 and the two images help direct it to the region. The probe  
6 with one or more apertures is sterile and preferably  
7 disposable. This biopsy method is shown, very schematically,  
8 in Fig. 11C.

9 In an alternative preferred embodiment of the  
10 invention, only the perforated plate through which the  
11 needle or elongate object is passed is an imaging array. In  
12 this case the array through which the needle passes give a  
13 two dimensional placement of the impedance abnormality while  
14 an imaging or non-imaging impedance sensor on the needle  
15 gives an indication of when the needle has reached the  
16 region of impedance abnormality, as described above.

17 Alternative guiding systems for frontal and lateral  
18 breast biopsy or for guiding an elongate element to a  
19 desired impedance region of the body are shown in Figs. 11D  
20 and 11E, respectively.

21 Fig. 11D shows a system for in which two relatively  
22 large plate multi-element probes 28, 30 are placed on  
23 opposite sides of the desired tissue, shown as a breast 160  
24 of a prone patient 161. Sensor array probes 28 and 30 are  
25 held in position by positional controller 181 via rotatable  
26 mounts 191. A mount 198 positions a biopsy needle 199 within  
27 the opening between probe arrays 28 and 30, and is operative  
28 to adjust its height. A suspicious region 183 which is  
29 located at positions 184 and 185 on arrays 28 and 30  
30 respectively as described herein, which information is  
31 supplied to a CPU 197, which determines the position of the  
32 suspicious region for controller 181. The controller then  
33 inserts the needle into the suspicious region, for example,  
34 to take the biopsy. Biopsy needle 199 is preferably of the  
35 type shown in Fig. 10 to further aid in positioning of the  
36 needle. As indicated above, this is not required for some

1   embodiments of the invention.

2           Alternatively, biopsy needle 199 may be inserted  
3   through holes formed between the elements of probes 28  
4   and/or 30 as described above. Furthermore, while automatic  
5   insertion of the biopsy needle is shown in Fig. 11D, manual  
6   insertion and guidance based on impedance images provided by  
7   the probes is also feasible.

8           Fig. 11E shows a system similar to that of Fig. 11D in  
9   which the imaging and biopsy needle insertion is from the  
10   side of the breast, rather than from the front. Operation of  
11   the method is identical to that of Fig. 11D, except that an  
12   additional probe 29 may be provided for further localization  
13   of suspicious region 183. Alternatively, one or two of the  
14   probes may be substituted by plates of inert material for  
15   holding and positioning the breast.

16           It should be noted that while the breast has been used  
17   for illustrative purposes in Figs. 11A through 11E, the  
18   method described is applicable to other areas of the body,  
19   with necessary changes due to the particular physiology  
20   being imaged.

21           Fig. 12 shows, very schematically, the intra-operative  
22   probe of Fig. 8 combined with a video camera 256 to more  
23   effectively correlate the impedance measurement with the  
24   placement of the probe on the body. An intra-operative probe  
25   140 preferably having a number of optically visible  
26   fiduciary marks 146 is placed on the suspect lesion or  
27   tissue. A video camera 256 sequentially views the area  
28   without the probe and the same area with the probe in place  
29   and displays a composite image on a video display 258 after  
30   processing by a processor 260. Processor 260 receives the  
31   impedance data from probe 140, determines the positions of  
32   the fiduciary marks from the video image and superimposes  
33   the impedance image on the video image, with or without the  
34   probe, which is displayed on display 258.

35           Fig. 13 shows a laparoscopic or endoscopic probe 250  
36   used in conjunction with a fiber-optic illuminator/imager

1 252. In this embodiment, the laparoscopic impedance probe,  
2 which is formed on a flexible, preferably extendible paddle,  
3 is viewed by the illuminator/imager which is preferably a  
4 video imager, which is well known in the art. Probe 250 can  
5 be either round or flat, depending on the region to be  
6 imaged. When the imager views a suspicious lesion or tissue,  
7 probe 250 is extended to determine the impedance properties  
8 of the lesion. The combination of probe 250 and imager 252  
9 may be incorporated in a catheter 254 or other invasive  
10 element appropriate to the region of the body being  
11 investigated.

12 Optically visible fiduciary marks 253 on probe 250 are  
13 preferably used to determine the position of probe 250  
14 within the video image of the tissue seen by fiber-optic  
15 illuminator/imager 252, in a manner similar to that  
16 discussed above with respect to Fig. 12.

17 In a preferred embodiment of a system using any of the  
18 biopsy needle, intra-operative probe, finger tip probe or  
19 other embodiments described above, an audible sound  
20 proportional to an impedance parameter measured by the  
21 needle or other sensor in or on the body is generated by the  
22 system computer. This feature may be useful in situations  
23 where the probe is placed in locations which are difficult  
24 to access visually, such as suspected lesions during  
25 surgery. Such an audible sound could include any kind of  
26 sound, such as a tone whose frequency is proportional to the  
27 measured parameter or similar use of beeps, clicks, musical  
28 notes, simulated voice or the like. This feature can also be  
29 used for non-surgical procedures such as rectal, vaginal or  
30 oral examinations, or other examinations.

31 Fig. 16 shows methods useful for estimating the depth  
32 of a lesion and also for determining if a image contains a  
33 true lesion or an artifact.

34 A breast or other region 160 is imaged by a probe 270,  
35 for example, the probe of Figs. 1-3 or Figs. 6A and 6B. The  
36 depth of a local impedance deviation can be estimated by

1 palpating the breast or other region by a finger 272 or a  
2 plunger 274. The displacement of the local deviation on the  
3 image will be maximized when the palpation is at the same  
4 level as the lesion. It should also be understood that,  
5 where palpation causes movement of the local deviation on  
6 the impedance image, this is an indication that the  
7 deviation is "real" and not an artifact.

8 In a similar manner, application of variable  
9 compression to the imaging probe will result in a variation  
10 of the distance from the probe to deviation under the probe.  
11 This distance variation will cause a corresponding variation  
12 in the size and intensity of the deviation, thus helping to  
13 verify that the deviation is not artifactual.

14 Alternatively or additionally, the probe can be moved  
15 along the surface of the tissue without moving the tissue.  
16 In this case, surface effects will have a tendency to either  
17 disappear or to move with the probe (remain stationary in  
18 the image) while real anomalies will move, on the image, in  
19 the opposite direction from the movement of the probe.

20 Alternatively or additionally, the probe and the tissue  
21 can be moved together without moving the underlying  
22 structure (such as the bones). Tissue lesions will remain  
23 relatively stationary in the image while bone artifacts will  
24 move in the opposite direction.

25 In operation, a system according to the present  
26 invention measures impedance between the individual sensing  
27 elements and some reference point (typically the signal  
28 source point) at some other place on the body. Generally, in  
29 order to produce an interpretable impedance image, the  
30 sensing elements in the multi-element probe should detect  
31 distortions in the electric field lines due solely to the  
32 presence of a local impedance difference between embedded  
33 tissue of one type (for example, a tumor) and surrounding  
34 tissue of another type (for example, normal adipose tissue).

35 To avoid distortion in the field lines, the reference  
36 point is typically placed far from the sensor array, all

1 sensing elements are all at ground or virtual ground, and  
2 the current drawn by the elements is measured. Since the  
3 probe is at ground (an equipotential) the electric field  
4 lines (and the current collected by the elements) are  
5 perpendicular to the surface of the multi-element probe. In  
6 principle, if there are no variations of impedance below the  
7 probe, each element measures the integrated impedance below  
8 the element. This first order assumption is used in the  
9 determination of the position and/or severity of a tumor,  
10 cyst or lesion. It is clear, however, that the multi-element  
11 probe covers only a portion of even the organ which is being  
12 imaged. The area outside the area of the probe is not at  
13 ground potential, causing the field lines to bend out at the  
14 periphery of the probe, biasing the edge of the impedance  
15 image.

16 To reduce this effect, a conductive "guard ring" is  
17 provided around the edge of the imaged area to draw in and  
18 straighten the field lines at the edge of the imaged area.  
19 This guard ring, if one is desired, can consist of merely  
20 ignoring the, presumably distorted, currents drawn by the  
21 elements at (or near) the edge of the probe and ignoring the  
22 measurements made by these elements.

23 Furthermore, to possibly reduce the baseline impedance  
24 contributed to the local impedance image by tissue between  
25 the remote signal source and the region near the probe, an  
26 additional reference electrode may be placed on the  
27 patient's body relatively near the multi-element probe. For  
28 example, if the source is placed at the arm of the patient  
29 and the breast is imaged from the front, a reference  
30 electrode for sensing a reference voltage can be placed at  
31 the front of the shoulder of the patient. The measured  
32 impedances are then reduced by the impedance value of the  
33 reference electrode. Alternatively, the impedance values of  
34 the elements of the multi-element probe are averaged to form  
35 a reference impedance, and the display of the impedance map  
36 is corrected for this reference impedance.

1        One way to substantially avoid at least some of the  
2 above- mentioned problems is to use the apparatus shown in  
3 Figs. 1-3. As indicated above, the apparatus incorporates  
4 two probe heads 28 and 30. The breast to be imaged is placed  
5 between the probe heads and the breast is compressed by the  
6 heads (although generally to a lesser degree than in X-Ray  
7 mammography) so that the breast forms a relatively flat  
8 volume and fills the region between the probes. It should be  
9 noted that, if the current is measured at each of the  
10 sensing elements in both probes, then two somewhat different  
11 images of the same region are generated. Avoidance of the  
12 problems also results when the two multi-element probes are  
13 not parallel as described above.

14        It should be noted that when used on breasts, the  
15 images produced by the pair of large, flat probes of Fig. 3  
16 have the same geometric configuration as standard  
17 mammograms. Furthermore if used in the same compression  
18 orientations, the impedance images can be directly compared  
19 to the corresponding mammograms. In one preferred embodiment  
20 of the invention, mammograms corresponding to the impedance  
21 images to be taken are digitized, using film scanning or  
22 other digitization means known in the art, and entered into  
23 the system computer. If the mammogram is already digital,  
24 such as may be provided by a digital mammogram, the image  
25 file can be transferred from the mammogram.

26        The mammograms and impedance images can be overlaid or  
27 otherwise combined to form a single image. Such an image  
28 could highlight those areas of the mammogram in which the  
29 impedance is particularly low or high. Such a combined image  
30 thus presents two independent readouts (impedance and  
31 radiographic density) of the same well defined anatomical  
32 region in a known geometric orientation, to facilitate  
33 interpretation, correlation with anatomy and localization.

34        It is well known that the resolution of objects in an  
35 impedance image is reduced with distance of the object from  
36 the probe. Thus, it is possible to estimate the distance of

1 the object from the two probes based on the relative size of  
2 the same object on the two different probes. As indicated  
3 above, two opposing views of the breast may be taken. This  
4 would provide further localization of the object.

5 In one mode, the sensing elements of one probe are all  
6 electronically floating while the elements of the other  
7 probe are at a virtual ground (inputs to sensing  
8 electronics), and a remote signal source is used, as  
9 previously described. After an image is obtained from the  
10 one probe, the roles of the two probes are reversed to  
11 obtain an image from the other probe.

12 Alternatively, if all of the elements of one of the  
13 flat probes are electrified to the same voltage and the  
14 measuring probe is kept at virtual ground, the currents  
15 drawn from and received by the elements of both probes form  
16 a two dimensional admittance image of the region between the  
17 probes.

18 In a further preferred embodiment of the invention, one  
19 or a few closely spaced sensing elements on one of the  
20 probes is electrified, and the others are left floating.  
21 This would cause a beam-like flow of current from the  
22 electrified elements to the other sensing elements on the  
23 other probe. The object would disturb this flow causing  
24 impedance variations which are strongest for those elements  
25 which are in the path of the current disturbed by the  
26 object. If a number of such measurements are made with, each  
27 with a different group of electrodes being electrified, then  
28 good information regarding the position of the object can be  
29 obtained.

30 In practice, as indicated above, orthogonal views of  
31 the breast are taken giving additional position information.

32 In preferred embodiments of the invention the breast is  
33 imaged at a plurality of frequencies and both the real and  
34 imaginary parts of the impedance are calculated. The  
35 sensitivity of the detection of malignant tissue is a  
36 function of frequency, and, for a particular frequency, is a

1 function of the impedance measure or characteristic used for  
2 imaging, for example, real part of the impedance (or  
3 admittance), imaginary part of the impedance (or  
4 admittance), absolute value of the impedance (or  
5 admittance), phase of the impedance (or admittance), the  
6 capacitance or some function of the impedance or of  
7 admittance components.

8 In a practical situation, an impedance measure should  
9 give the maximum contrast between a malignancy and non-  
10 malignant tissue. It is therefore desirable to determine the  
11 frequency or combination of frequencies which give maximum  
12 detectability and to determine it quickly. One method of  
13 determining the frequency is to perform swept frequency  
14 measurements and to use the frequency or combination of  
15 frequencies which results in the best contrast.  
16 Alternatively, a number of images taken at relatively close  
17 frequencies can be used. It is believed that for many  
18 purposes, at least four samples should be taken in the range  
19 between and including 100 and 400 Hz and, preferably, at  
20 least one or two additional images are taken at frequencies  
21 up to 1000 Hz.

22 A second method is to use a pulsed excitation and  
23 Fourier analysis to determine impedance over a range of  
24 frequencies. The optimum frequency or frequencies determined  
25 from the swept or pulsed measurement are then used in a  
26 single or multiple frequency measurement. A pulse shape  
27 which has been found useful in this regard is a bi-polar  
28 square pulse having equal positive and negative going pulses  
29 of 5-10 millisecond duration and fast rise and fall times.

30 A number of measures of the impedance, as described  
31 below, have been found useful for comparing different areas  
32 of the image. Generally, it is useful to display a gray  
33 scale or pseudo-color representation of the values of the  
34 impedance measure, either on a linear scale or where the  
35 square of the impedance measure is displayed. Also useful is  
36 an "absorption scale" where the value of an impedance

1 measure,  $v$ , is displayed as:

$$2 \quad d(v) = (\max - 1) * (\exp(v * (\max - 1) - 1)) / (e - 1),$$

3 where  $\max$  is the maximum normalized value of  $v$ . Generally,  
4 the display is most useful when the measure is normalized,  
5 either by division or subtraction of the minimum or average  
6 value of the measure in the display.

7 Furthermore, the display may be automatically windowed  
8 to include only those values of the impedance measure  
9 actually in the image, or to include a relative window of  
10 selectable size about the average value of the impedance  
11 measure. The range of values to be displayed may also be  
12 determined using a baseline average value measured at a  
13 region remote from irregularities, i.e., remote from  
14 the nipple of the breast. Alternatively, the baseline  
15 average may be a predetermined average value as measured for  
16 a large group of patients. Alternatively, a reference region  
17 on the image may be chosen by the user to determine the  
18 baseline average to be used for windowing.

19 While the display may show the exact measure for each  
20 pixel as is conventional, for example, in displays of  
21 nuclear medicine images, in a preferred embodiment of the  
22 invention the display is an interpolated image formed by  
23 quadratic or cubic spline interpolation of the impedance  
24 measure values. This type of display removes the annoying  
25 checkerboard effect of the relatively low resolution  
26 impedance image without any substantial loss of spatial or  
27 contrast detail.

28 The measures of impedance which have been found useful  
29 for comparing different areas of the image may be grouped as  
30 single frequency measures and polychromatic measures.

31 Single frequency measures include the admittance,  
32 capacitance, conductance and phase of the admittance. These  
33 measures may be measured at some predetermined frequency, at  
34 which the sensitivity is generally high, or at a frequency  
35 of high sensitivity determined by a preliminary swept or  
36 pulsed measurement.

1 Polychromatic impedance measures are generally based on  
2 a spectral curve based on fitting a set of capacitance (C)  
3 and conductance (G) values determined at a plurality of  
4 frequencies using linear interpolation, quadratic  
5 interpolation, cubic spline, band limited Fourier  
6 coefficients, or other methods known in the art.

7 One polychromatic measure is a spectral width measure.  
8 For a give pixel or region of interest the value of both the  
9 G and C parameters fall with frequency. The spectral width  
10 is the width of the spectrum (to a given percentage fall in  
11 the chosen parameter) as compared to the value at some low  
12 frequency, for example 100 Hz. If the parameter does not  
13 fall by the given percentage in the measured range it is  
14 assigned an impedance measure equal to the full measured  
15 bandwidth.

16 A second polychromatic measure is a spectral quotient  
17 in which the impedance measure is the ratio of the measured  
18 value of G or C parameters at two preset frequencies, which  
19 may be user selected, or which may be selected based on the  
20 swept or pulsed measurements described above. This measure,  
21 as all of the others may be displayed on a per-pixel basis  
22 or on the basis of a region of interest of pixels, chosen by  
23 the user.

24 A third type of polychromatic measure is based on a  
25 Relative Difference Spectrum determination. In this measure,  
26 the capacitance or conductance for a given region of  
27 interest (or single pixel) is compared to that of a  
28 reference region over the spectrum to determine a numerical  
29 difference between the two as a function of frequency. The  
30 thus derived Relative Difference Spectrum is then analyzed.  
31 For example, a spectral width measure as described above has  
32 been found to be a useful measure of abnormalities. Normally  
33 the width is measured where the relative difference spectrum  
34 passes from positive to negative, i.e., where the C or G is  
35 equal to that of the reference region.

36 A fourth type of polychromatic measure is based on a

1 Relative Ratio Spectrum determination. This is similar to  
2 the Relative Difference Spectrum, except that the ratio of  
3 the values between the reference area and the region of  
4 interest is used. A spectral width measure can be determined  
5 for this spectrum in the same manner as for the Relative  
6 difference Spectrum. Normally, the width is measured where  
7 the ratio is 1.

8 A fifth polychromatic measure which may be useful is  
9 the maximum of one of the other polychromatic measures, for  
10 example, the capacitance, conductance, Relative Difference  
11 Spectrum, Relative Ratio Spectrum, etc.

12 In impedance measurements of the breast in both men and  
13 women, normal breast tissue has a low capacitance and  
14 conductivity, except in the nipples, which have a higher C  
15 and G values than the surrounding tissue with the maximum  
16 obtained at the lowest frequency recorded, typically 100 Hz.  
17 The nipple capacitance and conductance remains higher than  
18 the surrounding tissue up to about 1400 Hz for fertile  
19 patients and up to about 2500 Hz for older patients (which  
20 is reduced to 1400 Hz for older patients by estrogen  
21 replacement therapy). These frequencies represent the normal  
22 range of spectral widths for the Relative and Difference  
23 Spectra. Tumors can be recognized by very high C and G  
24 relative ratio or relative difference values up to 2500 Hz  
25 or even higher.

26 Capacitance and conductance values are measured by  
27 comparing the amplitude and phase of the signal received by  
28 the sensing elements. Knowing both of these measures at the  
29 same points is useful to proper clinical interpretation. For  
30 example, as illustrated below in Fig. 14, a region of  
31 elevated conductivity and reduced capacitance (especially at  
32 relatively low frequencies, most preferably less than 500  
33 Hz, by generally below 2500 Hz and also below 10 kHz) is  
34 associated with benign, but typically pre-cancerous atypical  
35 hyperplasia while, as shown in Fig. 15, cancer typically has  
36 both elevated capacitance and conductivity over, generally,

1 a wide frequency range, as compared to the surrounding  
2 tissue. Proper differential diagnosis is aided by having the  
3 frequency samples be close enough together so that changes  
4 in the conductivity and capacitance in the low frequency  
5 range can be tracked. This also requires the display of both  
6 capacitance and conductance or the use of an impedance  
7 measure which is based on an appropriate combination of the  
8 two.

9 Methods for calculating C and G are given in the  
10 abovementioned US patents 4,291,708 and 4,458,694, the  
11 disclosures of which are incorporated herein by reference. A  
12 preferred embodiment of the invention takes advantage of the  
13 calibration capability inherent in the use of cover plates  
14 as shown in Figs. 5A and 5B. It can be shown that if the  
15 received waveform is sampled at a fixed spacing,  $\delta$ , such  
16 that N samples are taken in each cycle, then the real and  
17 imaginary values of the impedance can be determined as:

18  
19 
$$G = \Sigma (g_n (V_{(n+\frac{1}{2}N)} - V_n)),$$

20 and

21 
$$\omega C = \Sigma (c_n (V_{(n+\frac{1}{2}N)} - V_n)),$$

22 where  $g_n$  and  $c_n$  are constants determined by a calibration  
23 procedure and  $V_n$  is the voltage measured at the nth sampling  
24 point (out of N). The first sample is taken at zero phase of  
25 the reference signal.

26 One relatively easy way to determine the constants is  
27 to perform a series of measurements when cover plate is in  
28 contact with the sensing elements as described above and a  
29 known impedance is placed between the transmitter and the  
30 cover plate. Since N coefficients are required for  
31 determining  $g_n$  and  $c_n$  for each frequency, N values of  
32 admittance and N measurements are required. For example, if  
33  $N=4$  (four samples per cycle) four different measurements are  
34 taken and the sampled signal values are entered into the  
35 above equations to give N equations, which are then solved  
36 for the values of the coefficients. The higher the number of

1 samples, the greater the accuracy and noise immunity of the  
2 system, however, the calibration and computation times are  
3 increased.

4 Alternatively, fewer samples are taken and values for a  
5 number of measurements are averaged, both in the calibration  
6 and clinical measurements to reduce the effects of noise.

7 Artifactual abnormalities in the impedance image can be  
8 caused by such factors as poor surface contact or  
9 insufficient conductive coupling on some or all of the  
10 sensing elements, the presence of air bubbles trapped  
11 between probe and tissue and normal anatomical features such  
12 as bone or nipple.

13 Bubbles can be recognized by their typically lower C  
14 and G values compared to background, often immediately  
15 surrounded by pixels with much higher C and G. Bubbles can  
16 be verified and eliminated by removing the probe from the  
17 skin and repositioning it, and or by applying additional  
18 conductive coupling agent. Contact artifacts can be  
19 determined and accounted for in real time by translating the  
20 probe and viewing the image as described above. Artifacts  
21 either disappear or remain fixed with respect to the pixels,  
22 while real tissue features move, on the image, in a  
23 direction opposite from the motion of the probe.  
24 Additionally, as described above, if the tissue beneath the  
25 skin is physically moved, while the probe and skeletal  
26 structure is kept fixed, only real tissue features will  
27 move. If the feature remains static, it is either a skin  
28 feature or bone.

29 If as described above, the probe and the tissue are  
30 moved together without moving the underlying structure (such  
31 as the bones). Tissue lesions and surface effects will  
32 remain relatively stationary in the image while bone  
33 artifacts will move in the opposite direction, thus  
34 distinguishing them from other impedance deviations.

35 Fig. 14 shows one example of a display, according to a  
36 preferred embodiment of the invention. In this display,

1 capacitance and conductivity images at two positions on a  
2 breast are shown, together with an indication of the  
3 positions on the breast at which these images were acquired.

4 In particular, as seen in Fig. 15, the display includes  
5 the capability of displaying up to five sets of capacitance  
6 and conductance images in the five sets of smaller squares.  
7 These images are associated with probe areas indicated as  
8 numbers 1-5 on the breast image shown in the display. In  
9 practice, the examiner manipulates a joystick or other  
10 digital pointing device, such as device 105 shown in Fig.  
11 6A. This device is manipulated until a square is  
12 appropriately placed on the breast image. The examiner then  
13 presses a button which causes a pair of impedance images to  
14 be stored and displayed on the screen in an appropriate  
15 square, and the indicated position to be displayed on the  
16 physiological (breast) drawing. The small images are  
17 numbered from left to right. Preferably, the examiner can  
18 scale the physiological image so that the dimensions of the  
19 breast shown and the extent of the probe array are  
20 compatible. It should be understood that during the  
21 placement of the probe, real time images (acquired about  
22 once every 50-80 msec) of the capacitance and the  
23 conductance are shown, for example in the large squares to  
24 the left of the display.

25 Fig. 14, which represents an actual imaging situation  
26 shows, in the leftmost of the small images, a situation in  
27 which a small atypical hyperplasia which was previously  
28 detected by other means. This position shows an elevated  
29 conductivity and a very slightly reduced capacitance. In  
30 position 2, which is also shown in the two large squares to  
31 the right of the display, a previously unsuspected area  
32 having a capacitance/conductance profile characteristic of  
33 atypical hyperplasia is detected.

34 Fig. 15 shows a study typical of multiple suspected  
35 sites of carcinoma (in positions 2 and 4). The images of  
36 position 4 are shown in enlarged format at the left of the

1 image. In these sites, both the capacitance and conductance  
2 are elevated with respect to their surroundings.

3 Alternatively, a composite image such as the image of  
4 the sum of the capacitance and conductance images, their  
5 product, their sum or their ratio can be displayed to give a  
6 similar indication of the type of detected anomaly. A color  
7 coded composite image can also be displayed, where, for  
8 example, the median value for each image would be black and  
9 where positive and negative values would have a particular  
10 color which, when combined would result in distinctive  
11 colors for suspect impedance deviations.

12 The display shown in Figs. 14 and 15 can also be  
13 utilized to show a plurality of images of the same region at  
14 varying frequencies and one or more different impedance  
15 measures of a given region.

16 Figs. 17A and 17B show a block diagram of a preferred  
17 embodiment of a system 200 which incorporates a number of  
18 multi-element probes. It should be understood that the exact  
19 design of system for impedance imaging will depend on the  
20 types of probes attached to the system and the exact imaging  
21 modalities (as described above) which are used.

22 As shown in Figs. 17A and 17B the preferred system can  
23 incorporate biopsy needle probe 154, two plate probes 28, 30  
24 such as those shown in Figs. 1-3, scan zoom probe 100 such  
25 as that shown in Fig. 6A, conformal probe 139 such as that  
26 shown in Fig. 7B, a bra-cup probe, finger/glove probe 130  
27 such as that shown in Fig. 7A, laparoscopic probe 150 such  
28 as that shown in Fig. 9 or an intra-operative probe 140 as  
29 shown in Fig. 8. Furthermore, when three probes are used as  
30 in Fig. 11E, provision is made for attachment of a third  
31 plate probe. The position of the plate and needle probes is  
32 controlled by controller 181 as described in respect to Fig.  
33 11D.

34 The probes as connected via a series of connectors,  
35 indicated by reference numeral 302 to a selection switch 304  
36 which chooses one or more of the probes in response to a

1 command from a DSP processor 306. Selection switch 304  
2 switches the outputs of the probes, namely the signals  
3 detected at the sensing elements of the probes (or amplified  
4 versions of these signals) to a set of 64 amplifiers 308,  
5 one amplifier being provided for each sensing element. For  
6 those probes, such as the large plate probes, which have  
7 more than 64 sensing elements, the selection switch will (1)  
8 sequentially switch groups of 64 sensing elements to  
9 amplifier set 308, (2) choose a subset of sensing elements  
10 on a coarser grid than the actual array by skipping some  
11 elements, as for example every second element, (3) sum  
12 signals from adjacent elements to give a new element array  
13 of lower resolution and/or (4) choose only a portion of the  
14 probe for measurement or viewing. All of these switching  
15 activities and decisions are communicated to the switch by  
16 DSP processor 306 which acts on command from a CPU 312. The  
17 output of the amplifiers is passed to a multiplexer 307  
18 where the signals are serialized prior to conversion to  
19 digital form by a, preferably 12-bit, A/D convertor 310. A  
20 programmable gain amplifier 309, preferably providing a gain  
21 which is dependent on the amplitude of the signals, is  
22 optionally provided to match the signal to the range of the  
23 A/D convertor. The output of A/D 310 is sent to the DSP for  
24 processing as described above. In a preferred embodiment of  
25 the invention DSP 306 is based on a Motorola MC 68332  
26 microprocessor.

27 While 64 amplifiers has been chosen for convenience and  
28 lower cost, any number of amplifiers can be used.

29 The DSP calculates the impedance results and send the  
30 results to CPU 312 for display on a graphic data display 16,  
31 printing on a printer 18 or other output signals generation  
32 as described above by a light indicator 314 or a sound  
33 indicator 316.

34 Alternatively, the DSP directs signal sampling and  
35 averages together the samples or pre-processes them, sending  
36 the averaged or pre-processed samples to CPU 312, which then

1 performs the impedance calculations.

2       The CPU may also receive images from video camera 256,  
3 for example, when used with an intra-operative probe, from  
4 an endoscopic optics and camera system 320, for example when  
5 the camera views the outer surface of the laparoscopic probe  
6 or from an ultra sound imager 322, for example, in biopsy  
7 performance as shown in Figs. 11A and 11B. When an image is  
8 acquired from one of these cameras a frame grabber 324 is  
9 preferably provided for buffering the camera from the CPU.  
10 As described above, the CPU combines these images with the  
11 impedance images provided by one or more probes for display  
12 or other indication to the operator.

13       Fig. 15 also shows a programmable reference signal  
14 generator 326 which receives control and timing signals from  
15 the DSP. The reference signal generator generates excitation  
16 signals which are generally supplied, during impedance  
17 imaging, to reference probe 13, which, as described above,  
18 is placed at a point (or at more than one point) on the body  
19 remote from the region of impedance measurement. Signal  
20 generator 312 may produce a sinusoidal waveform, pulses or  
21 spikes of various shapes (including a bipolar square shape)  
22 or complex polychromatic waveforms combining desired  
23 excitation frequencies. Appropriate impedance calculations,  
24 in DSP 306 or in CPU 312, are implemented in accordance with  
25 the waveform of the excitation.

26       Where a breast is imaged and one of the two plates is  
27 used as the source of excitation, as described above, the  
28 output of signal generator is sent to the exciting plate  
29 (signal paths not shown for simplicity). A current overload  
30 sensor 330 is preferably provided after the signal generator  
31 to avoid overloads caused by short circuits between the  
32 reference probe and the imaging probe or ground.

33       Also shown on Fig. 17A is an internal calibration  
34 reference 332 which is preferably used for internal  
35 calibration of the system and for testing and calibration of  
36 the probes.

1       For internal testing and calibration, calibration  
2 reference 232 receives the signals generated by the  
3 programmable reference signals generator as passed to the  
4 selection switch, in series with an internal admittance in  
5 the calibration reference, as selected by the DSP processor.  
6 The DSP processor computes the admittance from signals  
7 received from the A/D convertor and compares the computed  
8 admittance with the actual admittance provided by internal  
9 calibration reference 332. This comparison can be provide an  
10 indication that the system requires adjustment or repair or  
11 can be used to calibrate the system.

12       Similarly, the output of calibration reference 332 may  
13 be provided to probe cover 88 for calibration and quality  
14 assurance of a plate or scan probe as described above. Under  
15 this situation, the DSP instructs selection switch 304 to  
16 choose the input from the respective probe.

17       Also provided is a user interface 334 such as a  
18 keyboard, mouse, joystick or combinations thereof, to allow  
19 the operator to enter positional information via the screen  
20 and to choose from among the probes provided and from the  
21 many options of calculation, display, etc.

22       Although described together as the preferred embodiment  
23 of the invention, it is not necessary to use the probes of  
24 the invention, the methods of calculation of impedance and  
25 impedance characteristics of the invention and the preferred  
26 apparatus of the invention together. While it is presently  
27 preferred that they be used together they may each be used  
28 with probes, calculation methods and apparatus for impedance  
29 imaging as applicable and as available.

30       Certain aspects of the invention have been described  
31 with respect to a biopsy needle or with respect to placement  
32 of such a needle. It should be understood that such  
33 description and aspects of the invention are equally  
34 applicable to positioning needles, catheters, endoscopes,  
35 etc.

36       Although various embodiments, forms and modifications

1 have been shown, described and illustrated above in some  
2 detail in accordance with the invention, it will be  
3 understood that the descriptions and illustrations are by  
4 way of example, and that the invention is not limited  
5 thereto but encompasses all variations, combinations and  
6 alternatives falling within the scope of the claims which  
7 follow:

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C L A I M S

- 1  
2 1. A multi-element probe for providing an electrical  
3 connection to a tissue surface comprising:  
4 a plurality of individual conductive sensing elements,  
5 each having a front portion suitable for contact with  
6 the tissue surface;  
7 a plurality of conductive elements providing an  
8 electrical connection to the respective individual sensing  
9 elements; and  
10 a partition separating the individual sensing elements  
11 such that when the individual probes contact the tissue  
12 surface they are substantially electrically isolated from  
13 each other.  
14  
15 2. A probe according to claim 1 wherein the sensing  
16 elements comprise a conductive, viscous gel.  
17  
18 3. A probe according to claim 1 wherein the sensing  
19 elements comprise a conductive, flexible, solid.  
20  
21 4. A probe according to claim 1 wherein the sensing  
22 elements comprise a sponge impregnated with a  
23 conductive viscous gel.  
24  
25 5. A probe according to claim 1 wherein each individual  
26 sensing element is located in a well formed by the partition  
27 and a substrate underlying the sensing element.  
28  
29 6. A probe according to claim 5 wherein the side of the  
30 substrate opposite the sensing elements is formed with an  
31 alignment structure for aligning the multi-element probe.  
32  
33 7. A probe according to claim 5 wherein the well is formed  
34 by embossing the partition on a sheet of material, whereby  
35 the un-embossed portion of the sheet forms the substrate  
36 underlying the sensing element.

1 8. A probe according to claim 6 wherein the well is formed  
2 by embossing the partition on a sheet of material, whereby  
3 the un-embossed portion of the sheet forms the substrate  
4 underlying the sensing element and wherein the indentations  
5 are the back of the embossed wells.

6

7 9. A probe according to claim 5 wherein the well is formed  
8 by laminating a grid formed by holes punched in a sheet or  
9 formed by extrusion to the substrate.

10

11 10. A probe according to claim 5 wherein the well is formed  
12 by printing the partitions onto the substrate.

13

14 11. A probe according to claim 5, including an electrical  
15 connection between a first surface of the substrate inside  
16 the well and a second, opposite, surface of the substrate.

17

18 12. A probe according to claim 11 and also comprising an  
19 anisotropic conductive sheet overlying the second surface of  
20 the substrate.

21

22 13. A probe according to claim 11 and also comprising a  
23 conductive contact on the second surface of the substrate  
24 which is electrically connected to the first surface of the  
25 substrate and an adhesive contact overlying the conductive  
26 contact.

27

28 14. A probe according to claim 1 wherein the sensing  
29 elements do not extend past the top of the partition.

30

31 15. A probe according to claim 14 wherein the sensing  
32 elements do not extend to the top of the partition.

33

34 16. A probe according to any of the preceding claims and  
35 including a cover having a conductive surface facing the  
36 front portion of the sensing elements.

1

2 17. A multi-element probe for providing an electrical  
3 connection to tissue comprising:

4 a plurality of individual conductive sensing elements,  
5 each having a front portion suitable for contact with the  
6 tissue;

7 a plurality of conductive elements providing an  
8 electrical connection to the respective individual sensing  
9 elements; and

10 a cover having a surface facing the front portion of  
11 the sensing elements, at least that portion of said surface  
12 facing the sensing elements being an electrically conductive  
13 surface.

14

15 18. A multi-element probe according to claim 17 wherein  
16 said cover is formed of a flexible material and wherein, in  
17 an unstressed position said electrical conductive surface  
18 does not contact said conductive sensing elements.

19

20 19. A multi-element probe according to claim 18 wherein  
21 said cover is so configured that the surface contacts the  
22 sensing elements when a surface of the cover opposite the  
23 conductive surface is pressed toward the sensing elements.

24

25 20. A multi-element probe according to claim 17 wherein the  
26 cover also includes an area, on the surface facing the  
27 individual sensing elements, remote from the individual  
28 sensing elements, which is a conductive area electrically  
29 connected to said portions facing the sensing elements, the  
30 multi-element probe also including a contact electrically  
31 connected to the exterior of the probe.

32

33 21. A multi-element probe according to claim 20 wherein, in  
34 an unstressed position, said electrical conductive surface  
35 does not contact said contact and wherein said cover is so  
36 configured that the conductive area contacts the contact

1 when a surface of the cover opposite the conductive surface  
2 is pressed toward the sensing elements.

3

4 22. A multi-element probe according to claim 17 and further  
5 comprising at least one contact suitable for connection to  
6 an external source of electrical energy and also including  
7 impedance elements between the conductive surfaces opposite  
8 the sensing elements and the contact.

9

10 23. A multi-element probe according to claim 20 and also  
11 including impedance elements between the conductive surfaces  
12 opposite the sensing elements and the contact.

13

14 24. A multi-element probe for providing an electrical  
15 connection to a tissue surface comprising:

16 a plurality of individual conductive sensing elements,  
17 each having a front portion suitable for contact with the  
18 tissue surface; and

19 a plurality of conductive elements providing an  
20 electrical connection to the respective individual sensing  
21 elements,

22 wherein the side of the substrate opposite the sensing  
23 elements is formed with indentations for aligning the multi-  
24 element probe.

25

26 25. A multi-element probe for the measurement of impedance  
27 of tissue, wherein the elements of the probe are  
28 sufficiently transparent to allow visualization of tissues  
29 beneath the probe when the probe is placed in contact with  
30 the tissues.

31

32 26. A multi-element probe for providing an electrical  
33 connection to a tissue surface comprising:

34 a plurality of individual conductive sensing elements,  
35 each having a front portion suitable for contact with the  
36 tissue surface; and

1 a plurality of conductive elements providing an  
2 electrical connection to the respective individual sensing  
3 elements, wherein

4 the probe is sufficiently transparent to allow  
5 visualization of tissues beneath the probe when the probe is  
6 placed in contact with the tissues.

7

8 27. A multi-element probe according to any of claims 1-16  
9 or 17-26, wherein the sensing elements are formed of a  
10 spongy conductive material.

11

12 28. A multi-element probe for providing an electrical  
13 connection to a tissue surface comprising:

14 a plurality of individual conductive sensing elements,  
15 each having a front portion suitable for contact with the  
16 tissue surface; and

17 a plurality of conductive elements providing an  
18 electrical connection to the respective individual sensing  
19 elements,

20 wherein the sensing elements are formed of a spongy  
21 conductive material.

22

23 29. A multi-element probe according to any of claims 1-16,  
24 17-26 or 28 wherein the sensing elements are formed on a  
25 flexible surface, whereby the multi-element probe conforms,  
26 at least in part, to the tissue.

27

28 30. A multi-element probe according to any of claims 1-16,  
29 17-26 or 28, wherein the probe is provided with apertures  
30 between sensing elements suitable for the passage of a thin  
31 elongate object.

32

33 31. A multi-element probe for providing an electrical  
34 connection to a tissue surface comprising:

35 a plurality of individual conductive sensing elements,  
36 each having a front portion suitable for contact with the

1 tissue surface; and

2 a plurality of conductive elements providing an  
3 electrical connection to the respective individual sensing  
4 elements,

5 wherein the probe is provided with apertures between  
6 sensing elements suitable for the passage of a thin elongate  
7 object.

8

9 32. A multi-element probe for providing an electrical  
10 connection to a tissue surface comprising:

11 an array of individual conductive sensing elements  
12 spaced over a surface, each element having a front portion  
13 suitable for contact with the tissue surface; and

14 a plurality of conductive elements providing an  
15 electrical connection to the respective individual sensing  
16 elements,

17 wherein the area of the conductive elements comprises  
18 less than 70% of the total area encompassed by the array.

19

20 33. A multi-element probe according to any of claims 1-16,  
21 17-26, 28, 31 or 32, wherein at least a portion of the  
22 surface of the probe facing the tissue to be measured is  
23 adhesive to the tissue.

24

25 34. A multi-element probe for providing an electrical  
26 connection to a tissue surface comprising:

27 a plurality of individual conductive sensing elements,  
28 each having a front portion suitable for contact with the  
29 tissue surface; and

30 a plurality of conductive elements providing an  
31 electrical connection to the respective individual sensing  
32 elements,

33 wherein at least a portion of the surface of the probe  
34 facing the tissue to be measured is adhesive to the tissue.

35

36 35. A multi-element probe according to any of claims 1-16,

1 17-26, 28, 31, 32 or 34, and including:

2 means for attaching the probe to the finger of a  
3 person whereby the person can perform palpative examination  
4 concurrently with impedance imaging.

5

6 36. A multi-element probe for providing an electrical  
7 connection to a tissue surface comprising:

8 a plurality of individual conductive sensing elements,  
9 each having a front portion suitable for contact with the  
10 tissue surface; and

11 a glove having fingers, said sensing elements being  
12 attached to the outside of one of the glove at one of the  
13 fingers whereby a wearer of the glove can perform palpative  
14 examination concurrently with impedance imaging.

15

16 37. A multi-element intermediate device for providing an  
17 electrical connection between a multiconductor sensor device  
18 and a tissue surface comprising a plurality of individual  
19 conductive sensing elements, substantially electrically  
20 insulated from each other, each having a front portion  
21 suitable for contact with the tissue surface and a back  
22 portion detachably matable to the multi-conductor sensor  
23 device.

24

25 38. An intermediate device according to claim 37 and  
26 including electrical contacts on the back portion which are  
27 electrically connected to the sensing element and which  
28 contact a plurality of mating contacts on the multi-  
29 conductor sensor device.

30

31 39. A multi-element intermediate device for providing an  
32 electrical connection between a multiconductor sensor device  
33 and a tissue surface comprising:

34 a multi-element probe according to any of claims 1-15,  
35 17-26, 28, 31, 32 or 34, and having a back portion  
36 detachably matable to the multi-conductor sensor device.

1 40. An intermediate device according to claim 39 and  
2 including electrical contacts on the back portion which are  
3 electrically connected to the sensing element and which  
4 contact a plurality of mating contacts on the multi-  
5 conductor sensor device.

6

7 41. A catheter or endoscopic probe comprising:

8 a multi-element probe according to any of claims 1-16,  
9 17-26 or 28; and

10 a fiber optic viewer whose field of view includes at  
11 least one surface of the probe when the probe is in contact  
12 with the tissue.

13

14 42. A catheter or endoscopic probe comprising:

15 a multi-element probe for providing an electrical  
16 connection to a tissue surface, the probe including a  
17 plurality of individual conductive sensing elements on a  
18 substrate, each sensing element having a front portion  
19 suitable for contact with the tissue surface and fiduciary  
20 marks visible from an other surface; and

21 a fiber optic viewer whose field of view includes at  
22 least the other surface of the probe.

23

24 43. Apparatus for impedance imaging of a breast comprising:

25 a multi-element probe comprising a plurality of sensing  
26 elements and adapted for mounting on one side of a breast;

27 an electrode adapted for mounting on a side of the  
28 breast substantially opposite the multi-element probe; and

29 a source of electrical energy which provides a voltage  
30 between at least a portion of the electrode and at least one  
31 element of the probe.

32

33 44. Apparatus for impedance imaging of a breast comprising:

34 a multi-element probe comprising a plurality of sensing  
35 elements and adapted for mounting on one side of a breast;

36 an electrode adapted for mounting on a side of the

1 breast substantially opposite the multi-element probe;  
2 an additional electrode adapted for mounting on portion  
3 of the body remote from the breast; and  
4 a source of electrical energy which provides a voltage  
5 between the additional electrode and at least one element of  
6 the probe.

7  
8 45. Apparatus according to claim 43 or claim 44 wherein the  
9 multi-element probe and the electrode adapted for mounting  
10 on a side of the breast form respective parallel planes.

11  
12 46. Apparatus according to claim 43 or claim 44 wherein the  
13 multi-element probe and the electrode adapted for mounting  
14 on a side of the breast form two planes at an angle to each  
15 other.

16  
17 47. Apparatus according to claim 43 or claim 44 and  
18 including a plurality of receivers which measure an  
19 electrical signal at the sensing elements.

20  
21 48. Apparatus according to claim 43 or claim 44 wherein the  
22 electrode adapted for mounting on a side of the breast  
23 comprises a second multi-element probe.

24  
25 49. Apparatus according to claim 43 wherein the multi-  
26 element probe comprises a multi-element probe according to  
27 any of claims 1-16, 17-26, 28, 31, 32 or 34.

28  
29 50. Apparatus according to claim 49 wherein at least one of  
30 the multi-element probes is rigid and non-planar in  
31 accordance with the shape of a body structure.

32  
33 51. Apparatus according to claim 49 wherein at least one of  
34 the multi-element probes is flexible so as to conform to the  
35 shape of a body structure.

36

- 1 52. Apparatus for impedance imaging of a breast comprising:  
2 a first multi-element probe comprising a plurality of  
3 sensing elements and adapted for mounting on one side of a  
4 breast;  
5 a second multi-element probe adapted for mounting on a  
6 side of the breast substantially opposite the multi-element  
7 probe; and  
8 a source of electrical energy which alternatively  
9 energizes at least some of the elements of one or the other  
10 of the first and second multi-element probes by supplying a  
11 voltage thereto, wherein the unenergized one of the multi-  
12 element probes forms an image based on the voltage applied  
13 to the energized probe.  
14
- 15 53. Apparatus according to claim 52 wherein the first and  
16 second multi-element probes form respective parallel planes.  
17
- 18 54. Apparatus according to claim 52 wherein the first and  
19 second multi-element probes form two planes at an angle to  
20 each other.  
21
- 22 55. Apparatus according to any of claims 52-54 and  
23 including a plurality of receivers which measure an  
24 electrical signal at the sensing elements.  
25
- 26 56. Apparatus according to claim 52 wherein the multi-  
27 element probe comprises a multi-element probe according to  
28 any of claims 1-16, 17-26, 28, 31, 32 or 34.  
29
- 30 57. Apparatus for impedance imaging of tissue comprising:  
31 an impedance probe which produces signals  
32 representative of impedance values below the elements and  
33 having fiduciary marks which are visible when the probe  
34 contacts the tissue;  
35 an impedance image generator which receives the signals  
36 and produces an impedance image;

1       a video camera which views the probe and tissue and  
2 generates a video image; and

3       a video image processor which receives a video image of  
4 the tissue without the probe in place and an image of the  
5 tissue with the probe in place, and provides a video image  
6 of the tissue with the fiduciary marks and impedance image  
7 superimposed thereon.

8

9   58. A method of impedance imaging of a region of the body  
10 comprising:

11       (a) positioning a multi-element probe, comprising a  
12 plurality of sensing elements, on one side of the region;

13       (b) positioning an electrode on a side of the region  
14 substantially opposite the multi-element probe;

15       (c) electrifying the electrode; and

16       (d) measuring a signal at at least some of the elements  
17 of the multi-element probe.

18

19   59. A method of impedance imaging of a region of the body  
20 comprising:

21       (a) positioning a multi-element probe, comprising a  
22 plurality of sensing elements, on one side of the region;

23       (b) positioning an electrode on a side of the region  
24 substantially opposite the multi-element probe;

25       (c) positioning a second electrode on a portion of the  
26 body;

27       (d) electrifying the second electrode; and

28       (e) measuring a signal at at least some of the elements  
29 of the multi-element probe.

30

31   60. A method according to claim 58 or claim 59 wherein (b)  
32 comprises positioning a second multi-element probe on a side  
33 of the region substantially opposite the multi-element  
34 probe.

35

36   61. A method of impedance imaging of a region of the body

1 comprising:

2       positioning a first multi-element probe, comprising a  
3 plurality of sensing elements, on one side of the region;  
4       positioning a second multi-element probe on a side of  
5 the region substantially opposite the multi-element probe;  
6       electrifying fewer than all of the plurality of  
7 sensing elements of the second multi-element probe; and  
8       measuring a signal at at least some of the elements of  
9 the first multi-element probe.

10

11 62. A method of impedance imaging of a region of the body  
12 comprising:

13       contacting one side of the region with a first multi-  
14 element probe, comprising a first plurality of sensing  
15 elements;

16       contacting a second side of the region with a second  
17 multi-element probe, comprising a second plurality of  
18 sensing elements;

19       receiving signals from said first and second multi-  
20 element probes in response to a stimulus; and

21       combining the signals received from both probes to  
22 locate objects within the region.

23

24 63. A method for guidance in the placement of an elongate  
25 element in a region of a subject comprising:

26       (a) inserting the elongate element into tissue, said  
27 element including a plurality of impedance measuring sensing  
28 element thereon;

29       (b) measuring the impedance between the plurality of  
30 sensing elements and an electrode in contact with the  
31 subject; and

32       (c) guiding the element to a desired position having  
33 defined impedance properties in response to measurements of  
34 impedance made in (b).

35

36 64. A method according to claim 63 and also including;

1        imaging the region of the subject including the  
2        elongate element and generating an image thereof;  
3        receiving the image and the measurements of impedance  
4        made in (b) and superimposing a representation of the  
5        impedance measurements on the image of the elongate element  
6        and surrounding tissues; and  
7        displaying said superimposed images.

8  
9        65. A method according to claim 64 wherein the outer  
10       surface of the elongate element is formed with a matrix of  
11       impedance measuring elements each measuring the tissue  
12       impedance in a direction generally perpendicular to the  
13       element and wherein the display indicates a guiding  
14       direction for the elongate element based on the impedance  
15       measurements.

16  
17       66. A method according to any of claims 63-65 wherein the  
18       elongate element is inserted into the body through a hole in  
19       an array of impedance probe elements and including:  
20       providing a two-dimensional impedance image based on  
21       signals received by the array;  
22       guiding the elongate element based on the two-  
23       dimensional image; and  
24       determining the desired depth of the elongate element  
25       based on impedance signals received from the impedance  
26       measuring elements on the elongate element.

27  
28       67. A method for guidance in the placement of an elongate  
29       element in portion of a patient comprising:  
30       forming a first two-dimensional impedance image of at  
31       least a part of said portion from a given direction;  
32       forming a second two dimensional impedance image of at  
33       least a part of the portion using a multi-element impedance  
34       probe placed at a known angle to the plane of the first  
35       image;  
36       inserting the elongate element between elements of the

1 multi-element probe; and  
2 guiding the elongate element to a point of impedance  
3 deviation at least partially under the guidance of the first  
4 and second two dimensional images.  
5

6 68. A method comprising:

7 providing an impedance measurement system including a  
8 multi-element probe attached to at least one finger of an  
9 examiner; and

10 providing an indication of impedance generated on the  
11 basis of signals detected by said elements, whereby both a  
12 tactile and impedance indication of an examined tissue are  
13 simultaneously acquired.  
14

15 69. A method for improving the sensitivity of impedance  
16 imaging comprising:

17 contacting tissue with a multi-element probe;  
18 contacting a different portion of tissue with at least  
19 one electrode;

20 exciting the at least one electrode with a pulsed  
21 voltage;

22 measuring signals, responsive to said pulsed voltage at  
23 at least a plurality of the elements of the probe;

24 computing the real and imaginary parts of an admittance  
25 represented by said voltage and signals for a plurality of  
26 frequencies at a plurality of said elements; and

27 choosing at least one frequency as a measurement  
28 frequency which gives a large difference for said measures  
29 at different elements of the probe.  
30

31 70. A method for identifying, in a multi-element impedance  
32 probe which forms an impedance map of tissue when placed on  
33 the surface thereof, artifacts among impedance deviations  
34 from the surroundings, the method comprising:

35 manipulating the tissue underlying the probe while the  
36 probe remains in stationary contact with the surface of the

1 tissue; and

2 identifying as a non-artifact those impedance  
3 deviations which shift in the direction of the manipulation  
4 on the impedance map.

5

6 71. A method for identifying, in a multi-element impedance  
7 probe which forms an impedance map of tissue when placed on  
8 the surface thereof, artifacts among impedance deviations  
9 from the surroundings, the method comprising:

10 moving the probe along the surface of the tissue; and

11 identifying as an artifact those impedance deviations  
12 which remain stationary or disappear in the impedance map as  
13 the probe is moved.

14

15 72. A method for identifying, in a multi-element impedance  
16 probe which forms an impedance map of tissue when placed on  
17 the surface thereof, artifacts among impedance deviations  
18 from the surroundings, the method comprising:

19 moving the probe together with the tissue; and

20 identifying as a fixed artifact those impedance  
21 deviations which move on the impedance map, in the opposite  
22 direction from the movement of the probe and the tissue.

23

24 73. A method of displaying impedance imaging information  
25 comprising:

26 displaying at least one impedance image of a region;  
27 and

28 displaying an indication of the imaged region on a  
29 representation of the physiology of the patient.

30

31 74. A method of displaying according to claim 73 and  
32 including:

33 simultaneously displaying both a capacitance and a  
34 conductance map of the same region.

35

36 75. A method of displaying impedance imaging information

- 1 comprising:  
2 displaying a capacitance map of a region; and  
3 simultaneously displaying a conductance map of the same  
4 region.  
5
- 6 76. A method of displaying impedance imaging information  
7 comprising:  
8 computing maps of a plurality of imaging measures; and  
9 simultaneously displaying the measures.  
10
- 11 77. A method of displaying impedance information  
12 comprising:  
13 computing a plurality of maps of at least one imaging  
14 measure at a plurality of frequencies; and  
15 simultaneously displaying the maps.  
16
- 17 78. A method of identifying a suspected carcinoma  
18 comprising:  
19 comparing a capacitance map of a region to a  
20 conductance map of the same region;  
21 identifying a deviation from the surroundings as a  
22 suspected cancer if at some frequency less than about 10 kHz  
23 both the capacitance value and the conductance value are  
24 higher than that of the surroundings.  
25
- 26 79. A method of identifying a suspected atypical  
27 hyperplasia comprising:  
28 comparing a capacitance map of a region to a  
29 conductance map of the same region;  
30 identifying a deviation from the surroundings as a  
31 suspected cancer if at some frequency less than 10 kHz both  
32 the capacitance value and the conductance value are higher  
33 than that of the surroundings.  
34
- 35 80. A method of differentiating a suspected carcinoma from  
36 a suspected atypical hyperplasia comprising:

1       comparing a capacitance map of a region to a  
2 conductance map of the same region;  
3       classifying a deviation from the surroundings as a  
4 suspected atypical hyperplasia if at some frequency less  
5 than 10 kHz the capacitance value is lower than that of the  
6 surroundings and the conductance value is higher than that  
7 of the surroundings; and  
8       classifying a deviation from the surroundings as a  
9 suspected cancer if at some frequency less than 10 kHz both  
10 the capacitance value and the conductance value are higher  
11 than that of the surroundings.

12

13   81. A method according to any of claims 78 to 80 wherein  
14 the frequency at which the comparison of the capacitance and  
15 conductance values take place is below 2500 Hz.

16

17   82. A method according to any of claims 78 to 80 wherein  
18 the frequency at which the comparison of the capacitance and  
19 conductance values take place is below 500 Hz.

20

21

22

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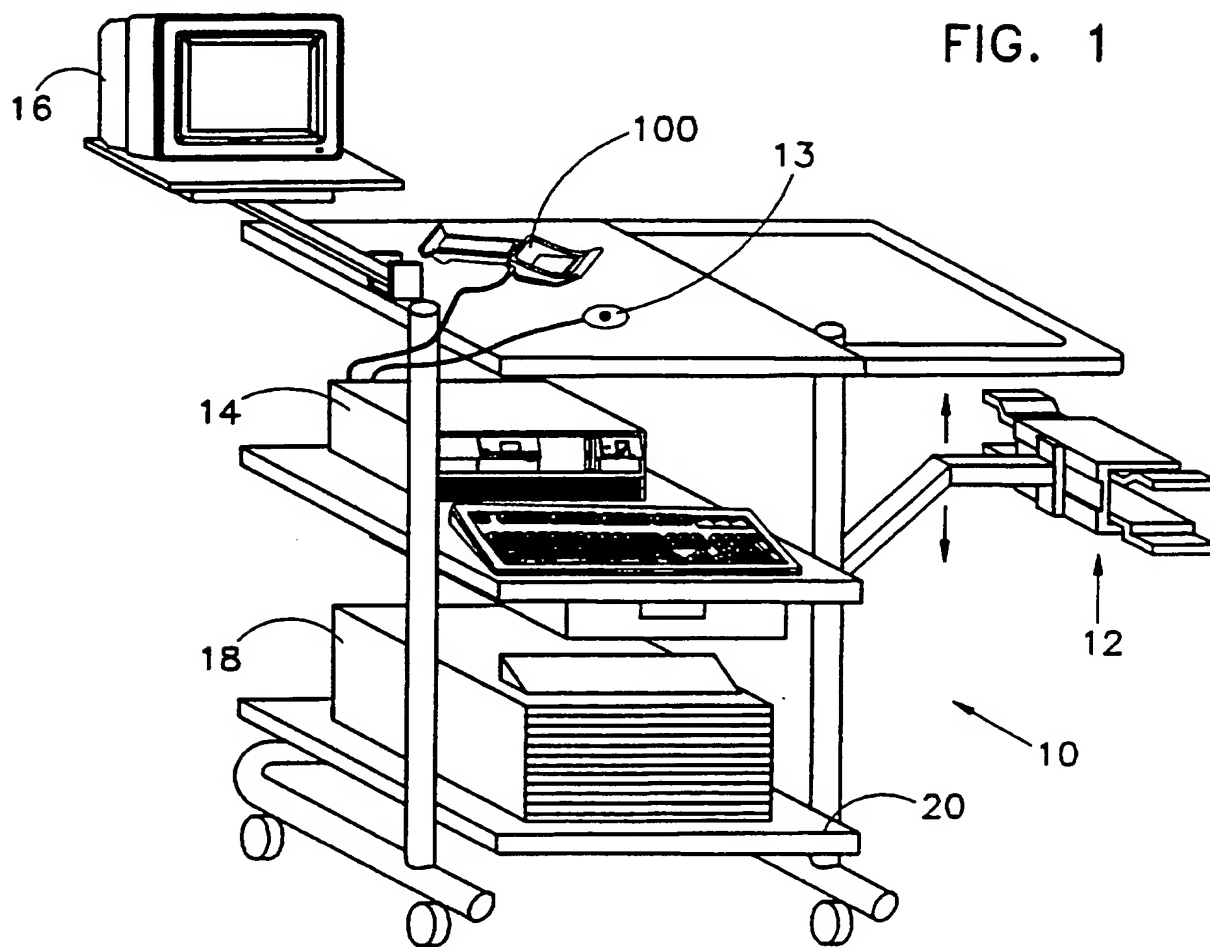
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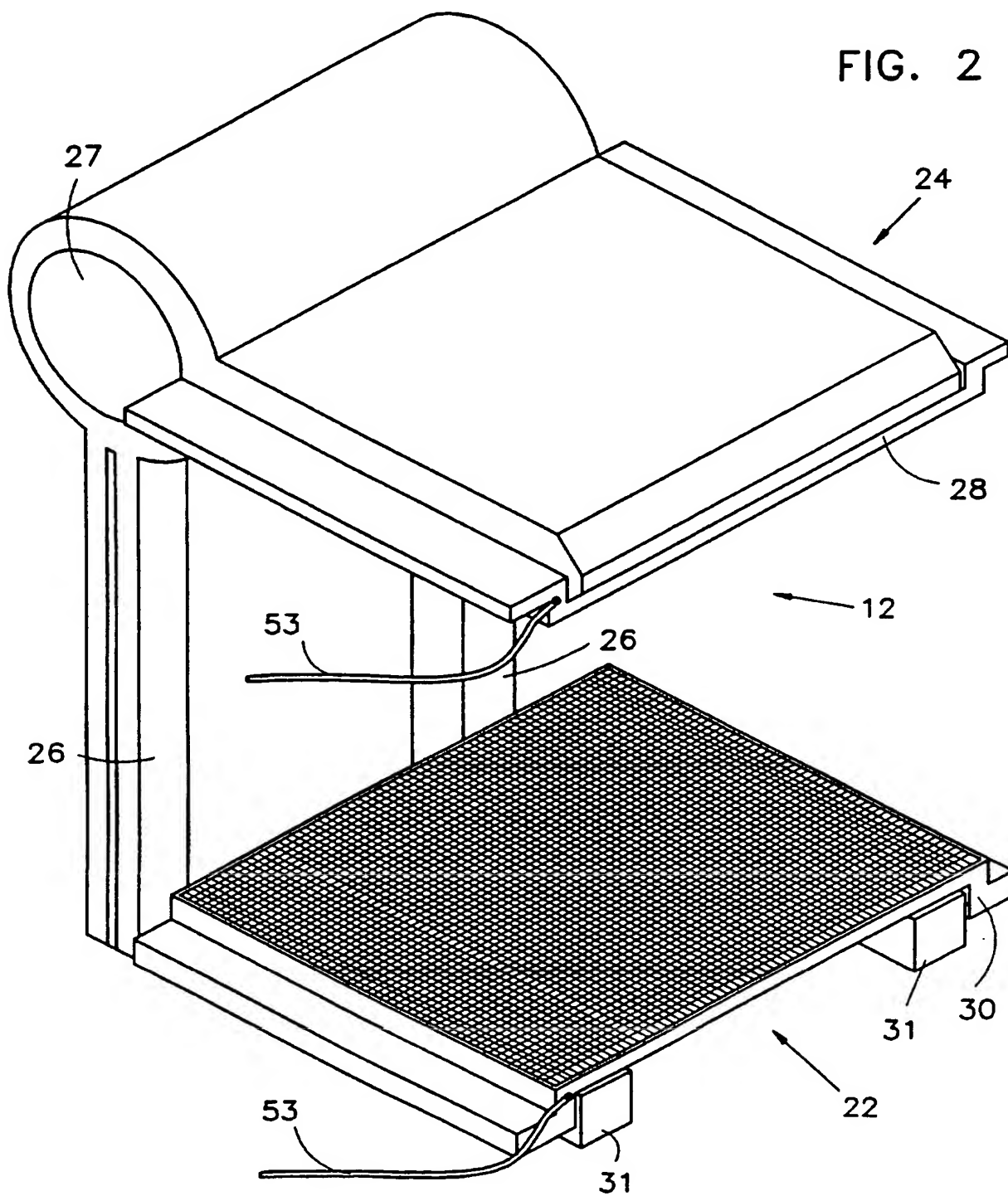
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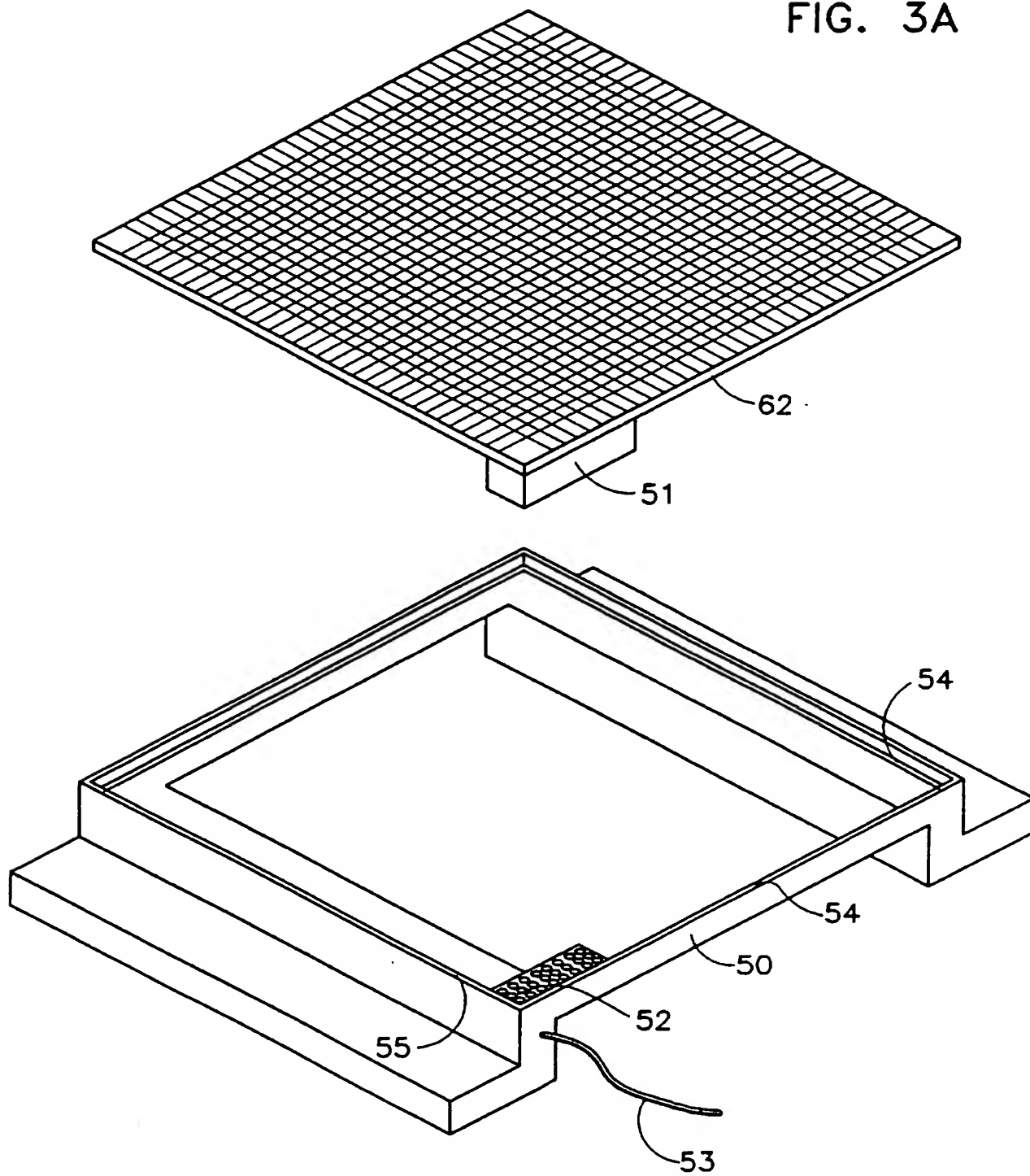
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FIG. 2



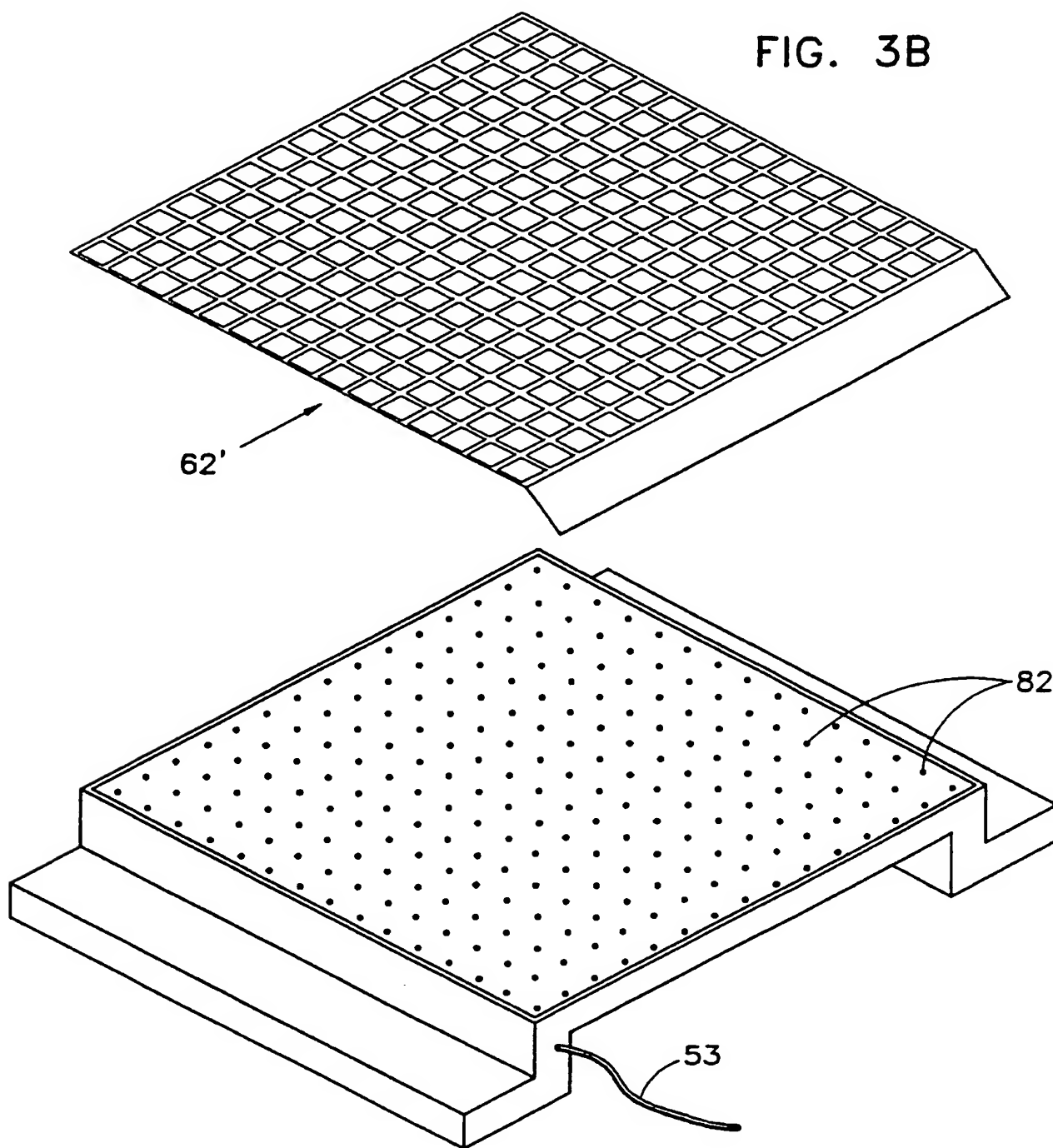
3/22

FIG. 3A



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FIG. 3B



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FIG. 4

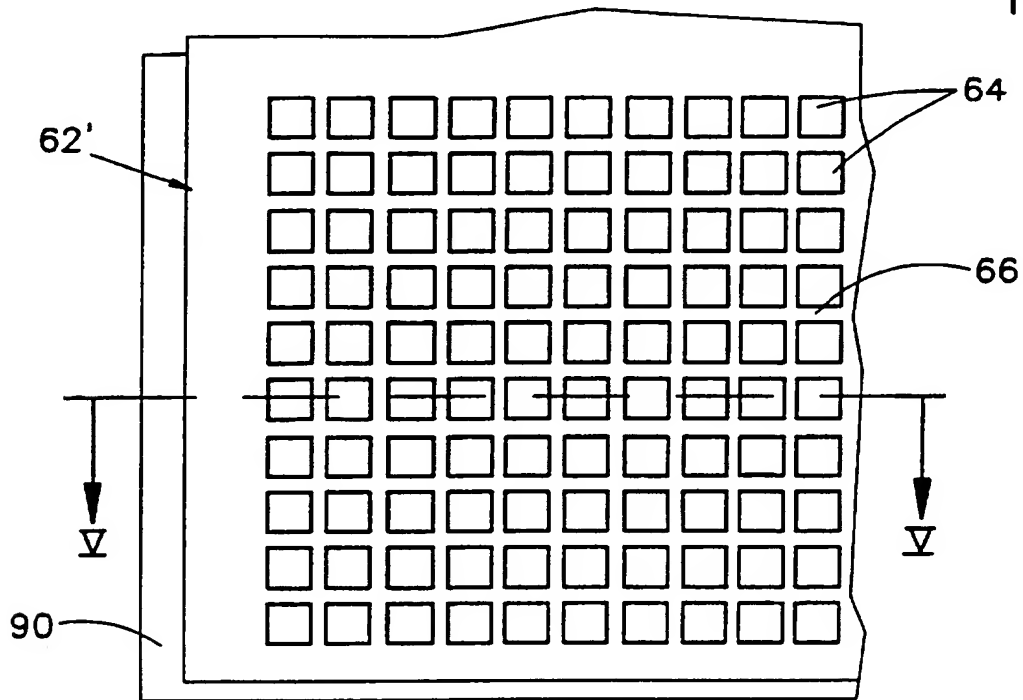
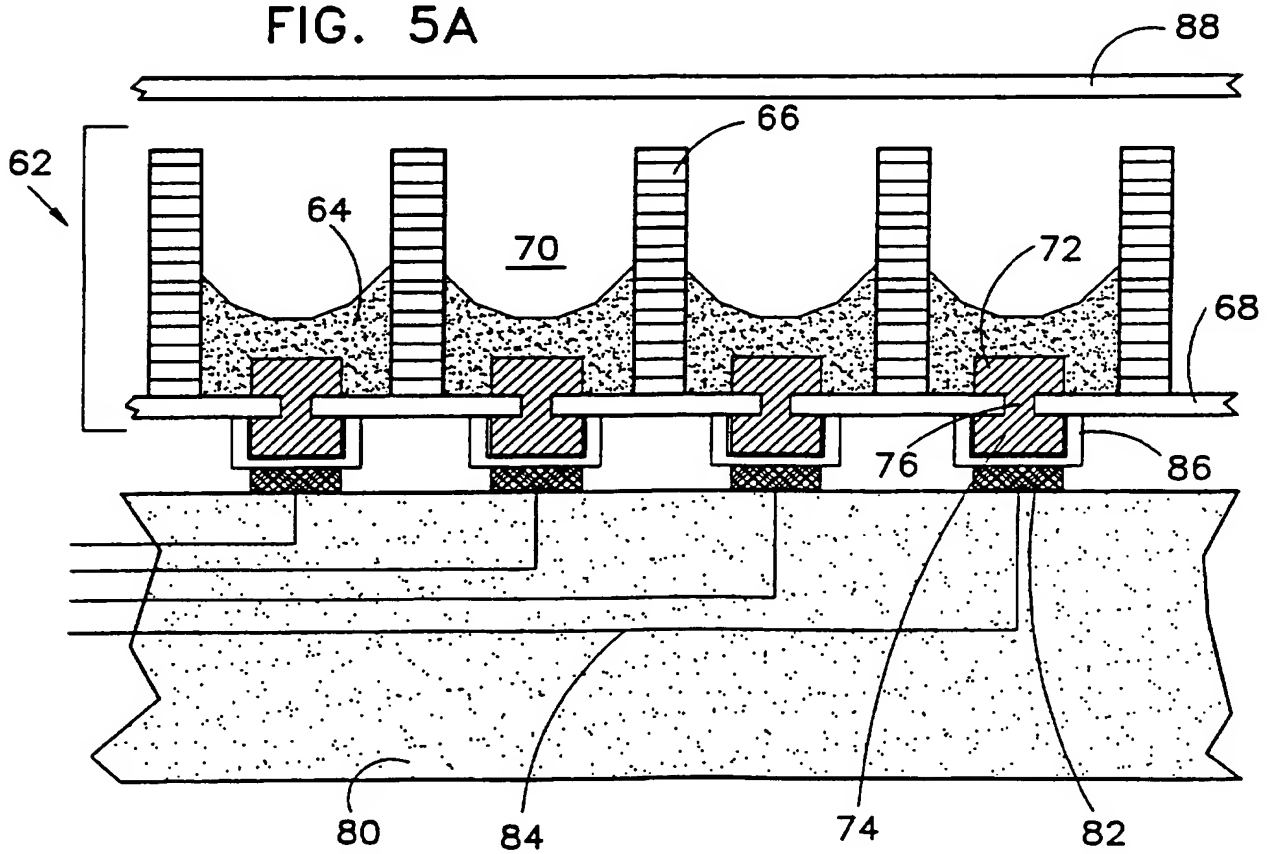
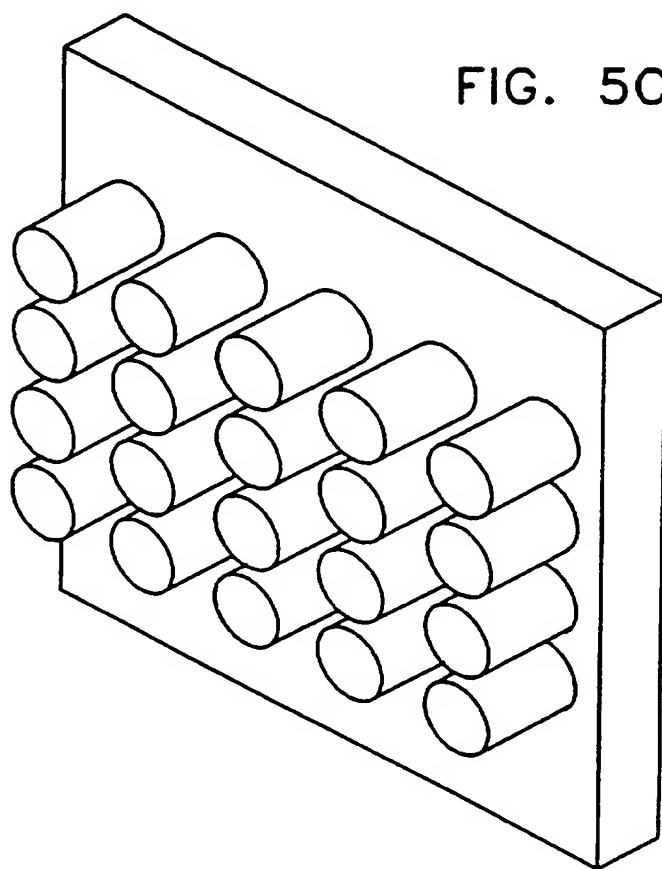


FIG. 5A



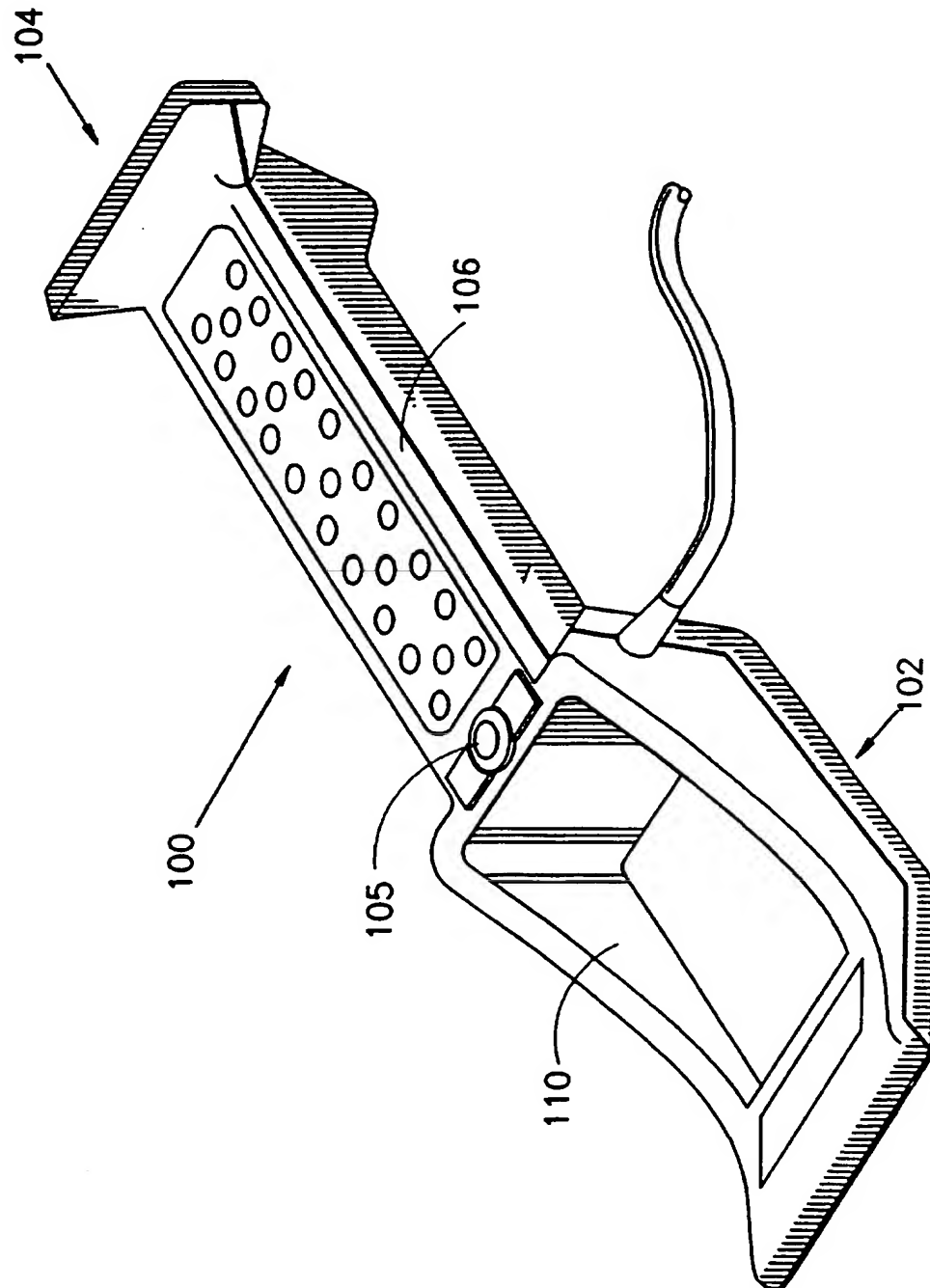


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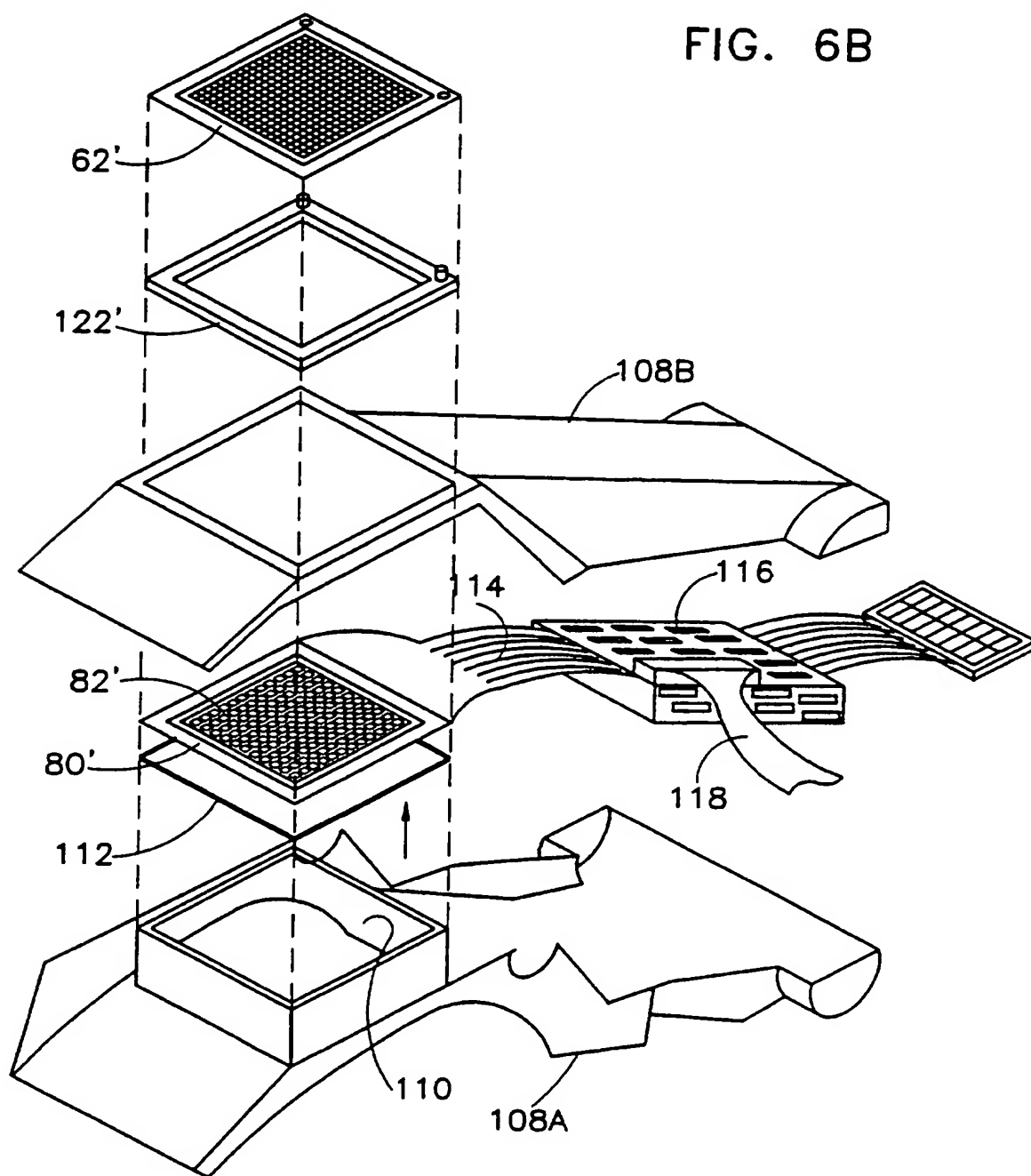
8/22

FIG. 6A



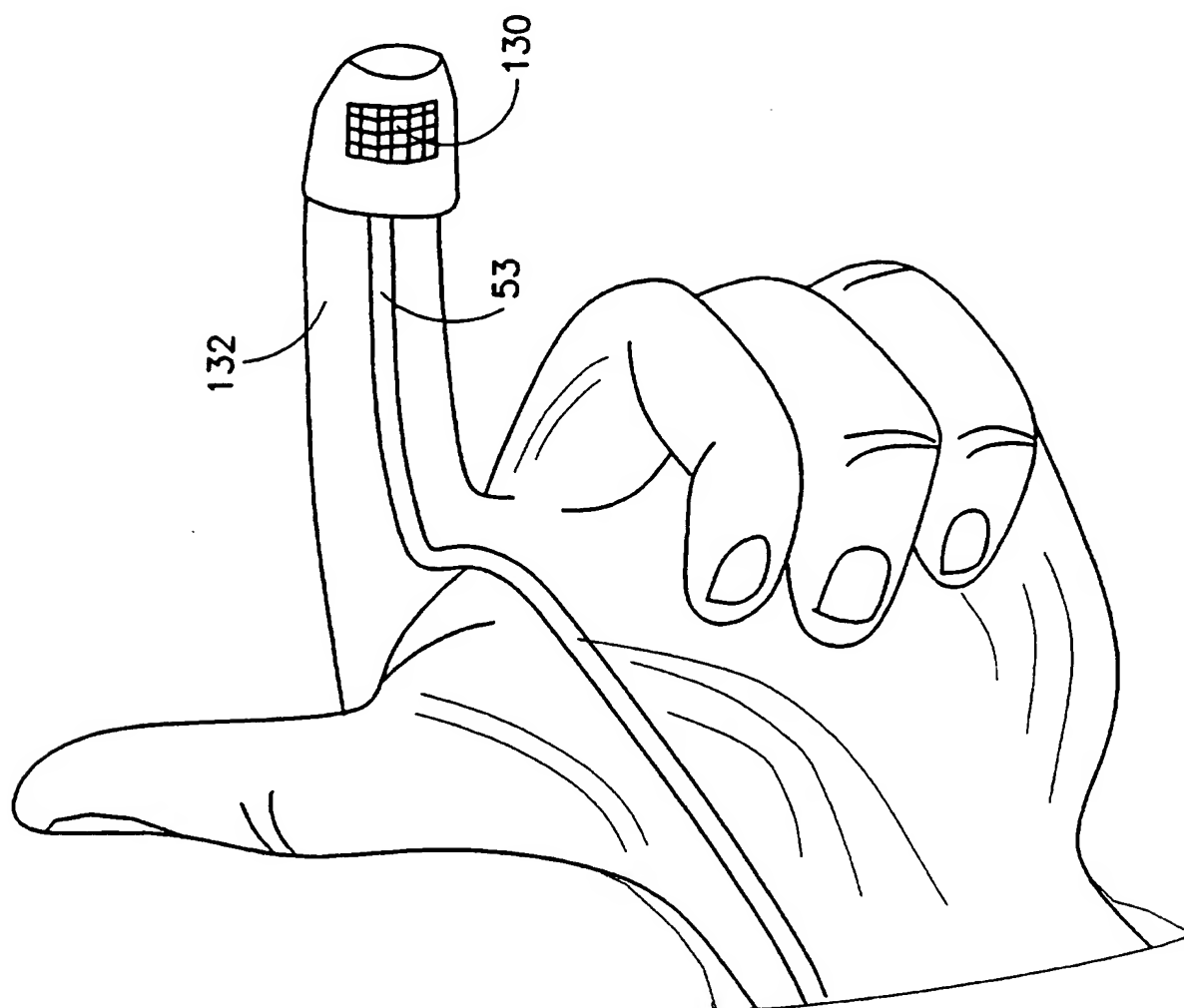
9/22

FIG. 6B



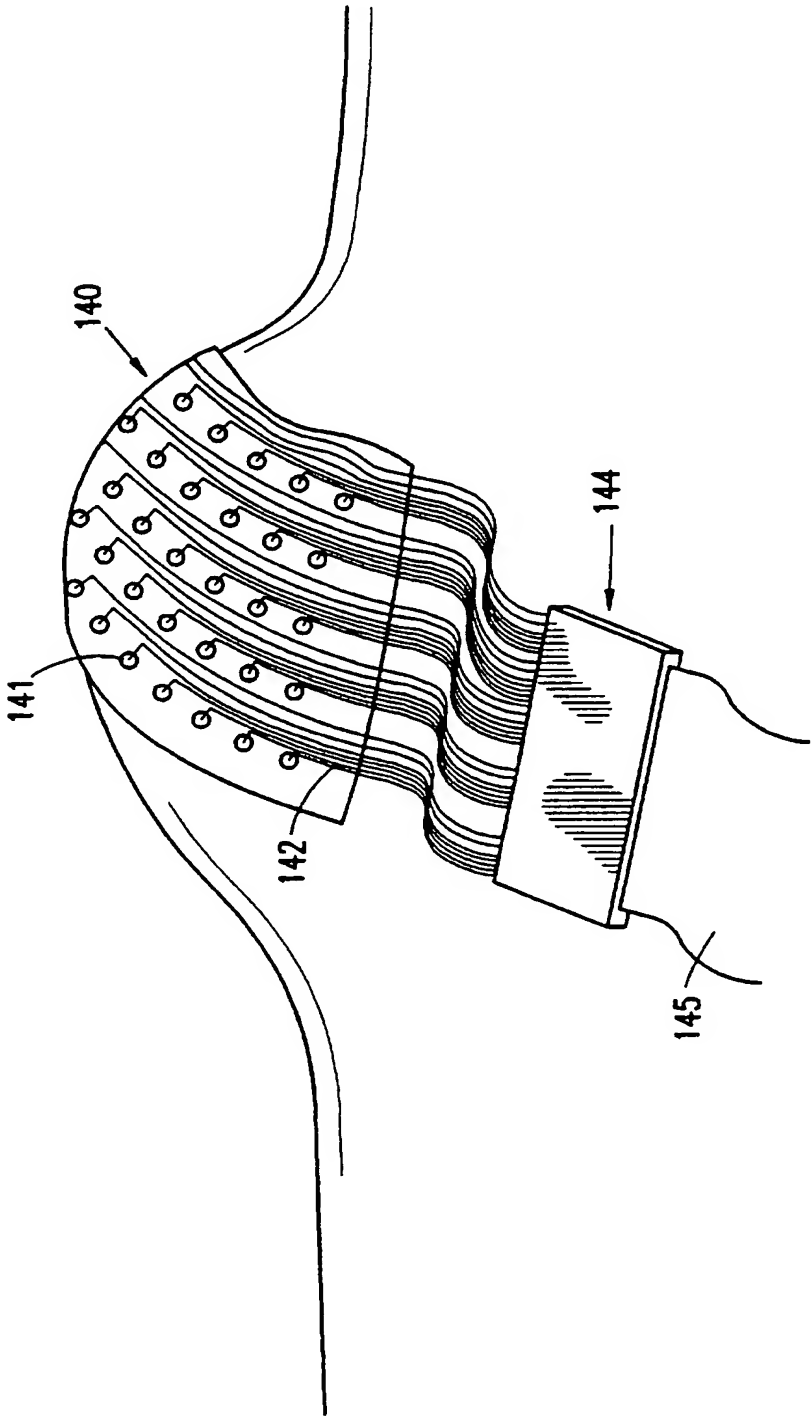
10/22

FIG. 7A



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FIG. 7B



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FIG. 10

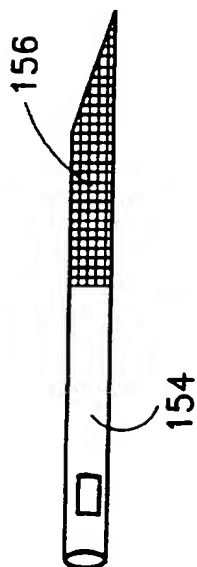


FIG. 8

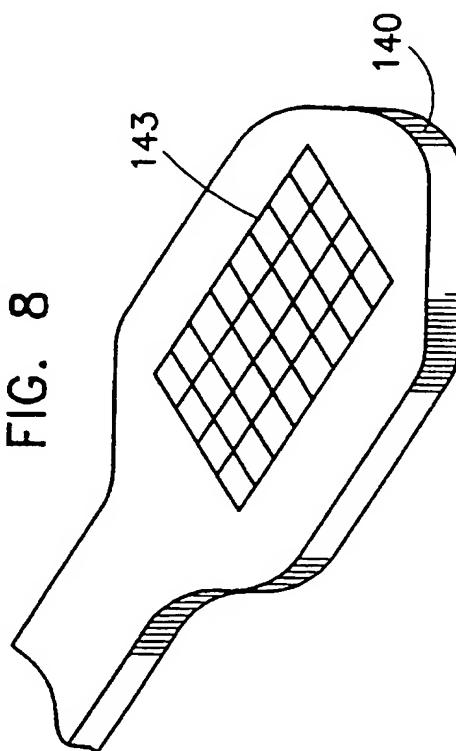
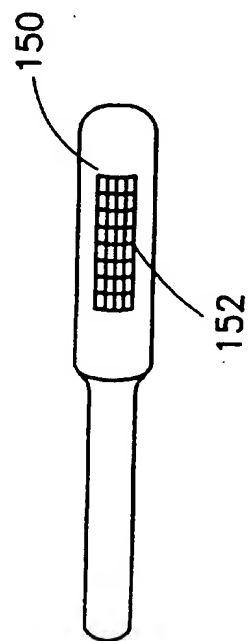


FIG. 9



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FIG. 11A

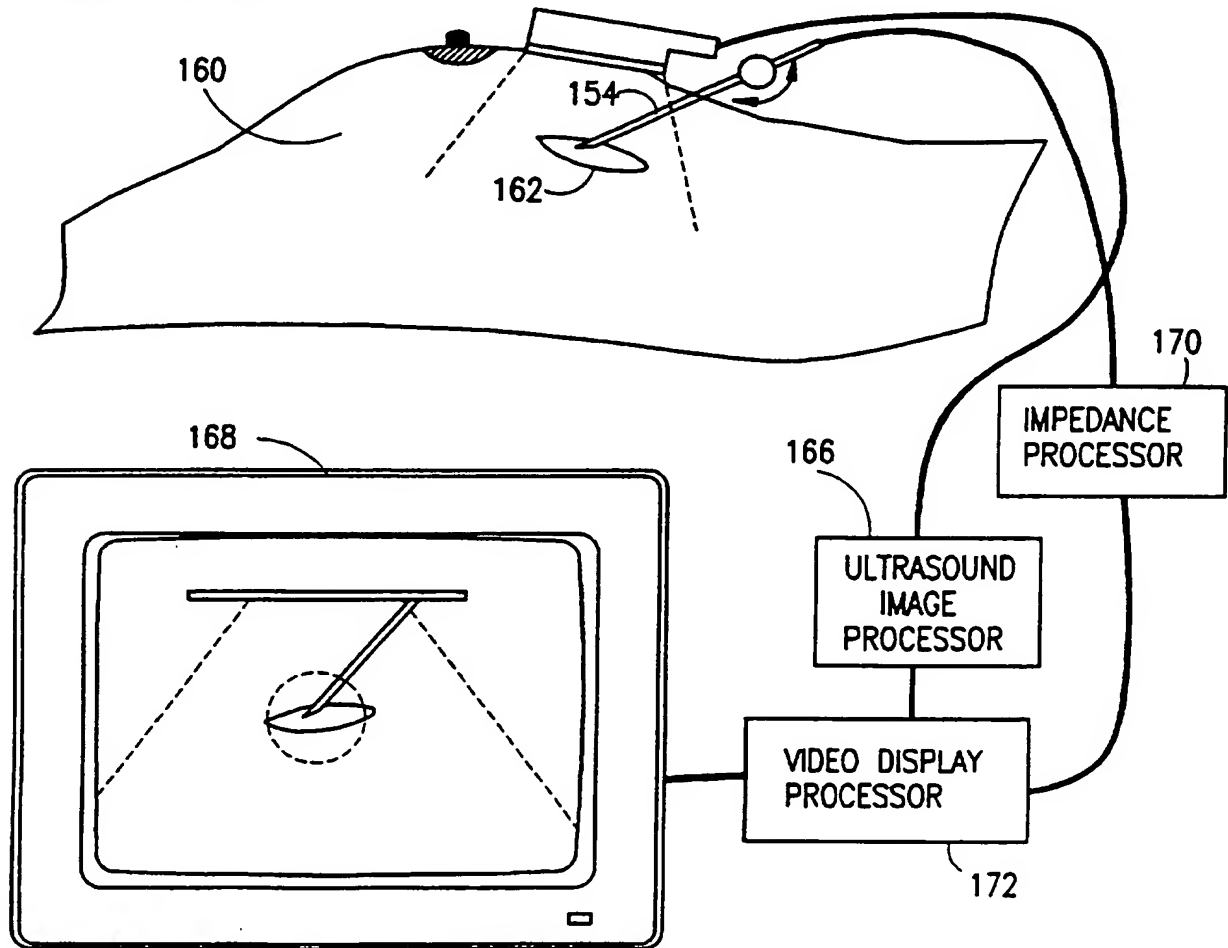
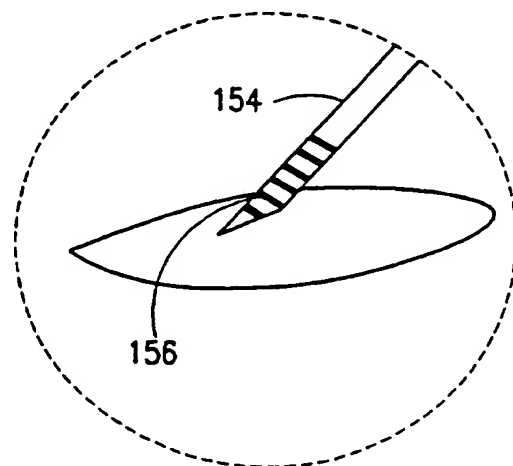


FIG. 11B



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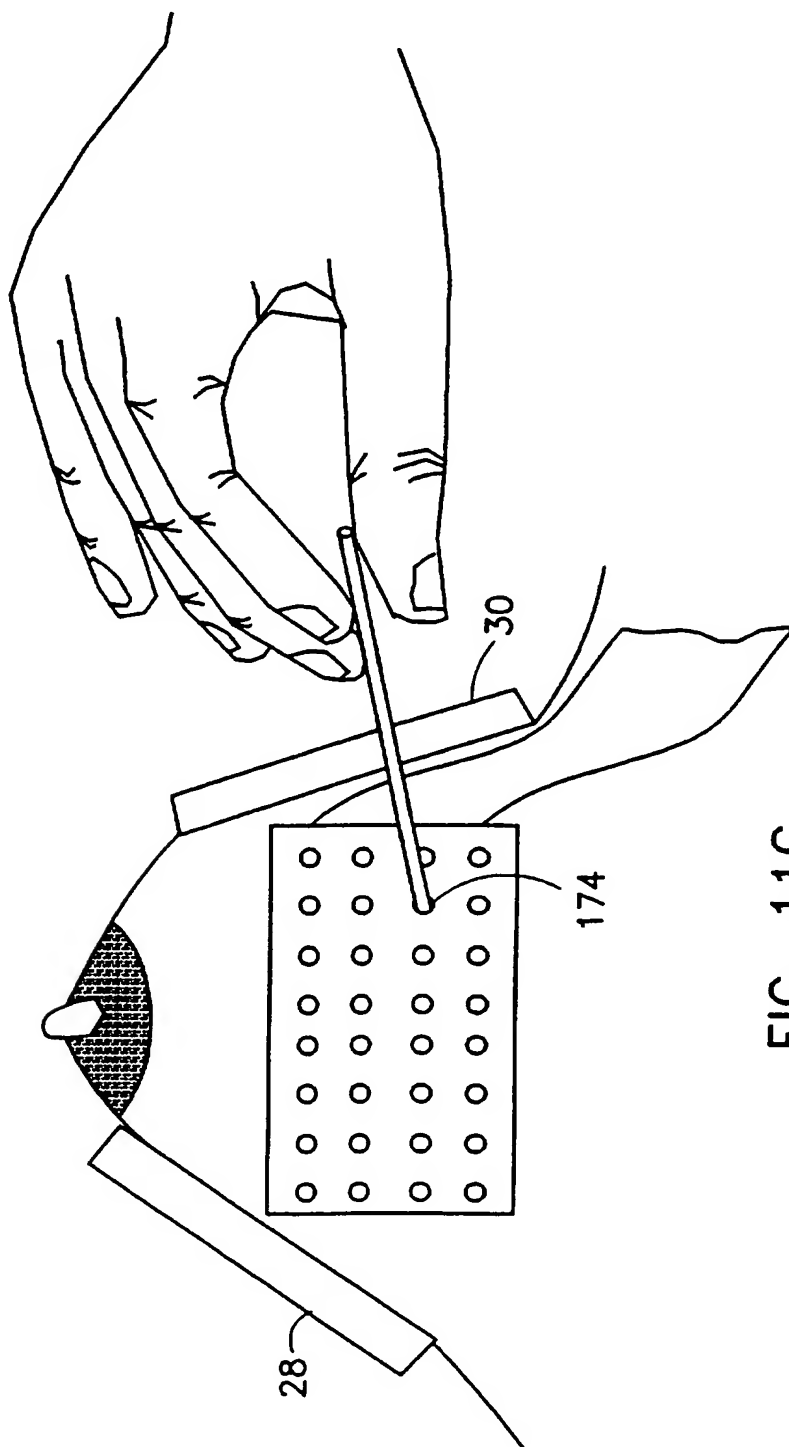


FIG. 11C

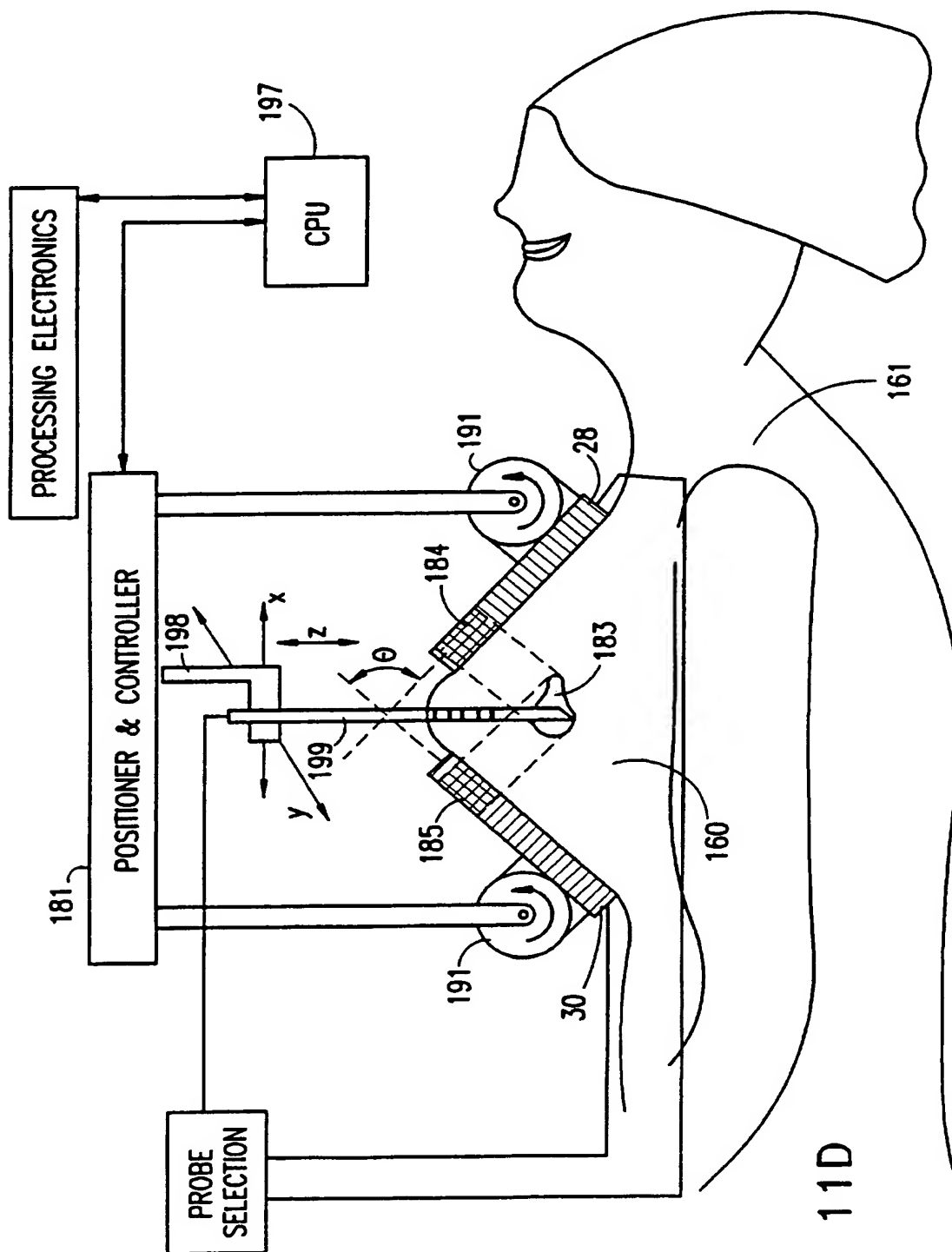


FIG. 11D



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FIG. 12

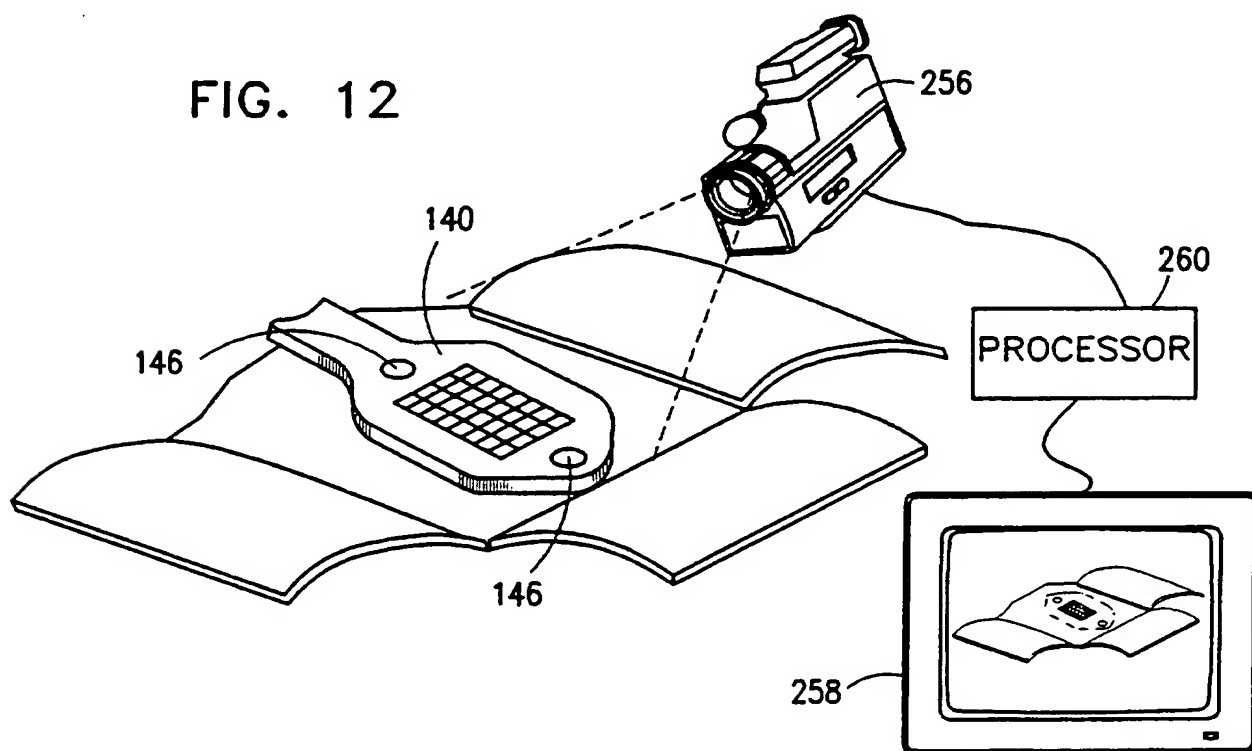
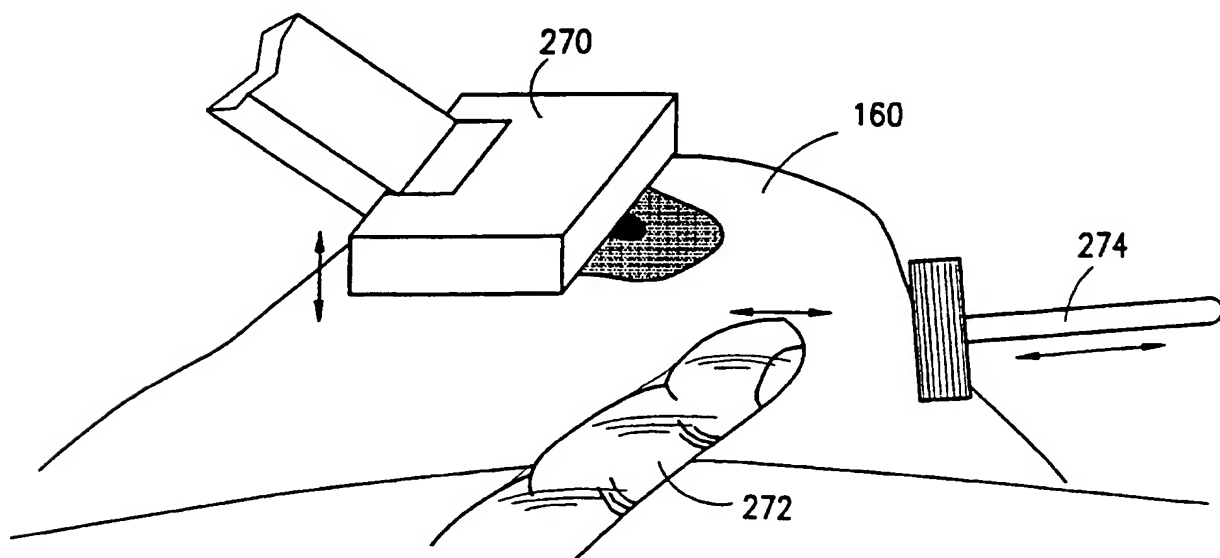
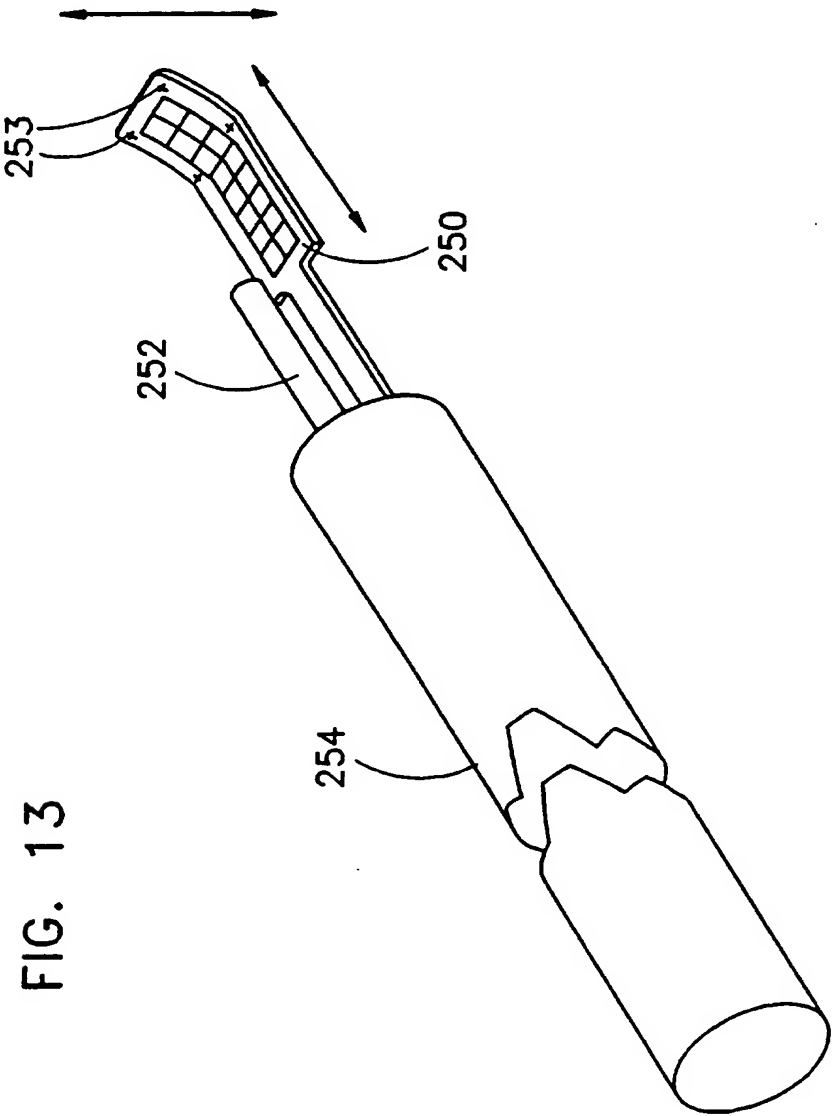


FIG. 16





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FIG. 14

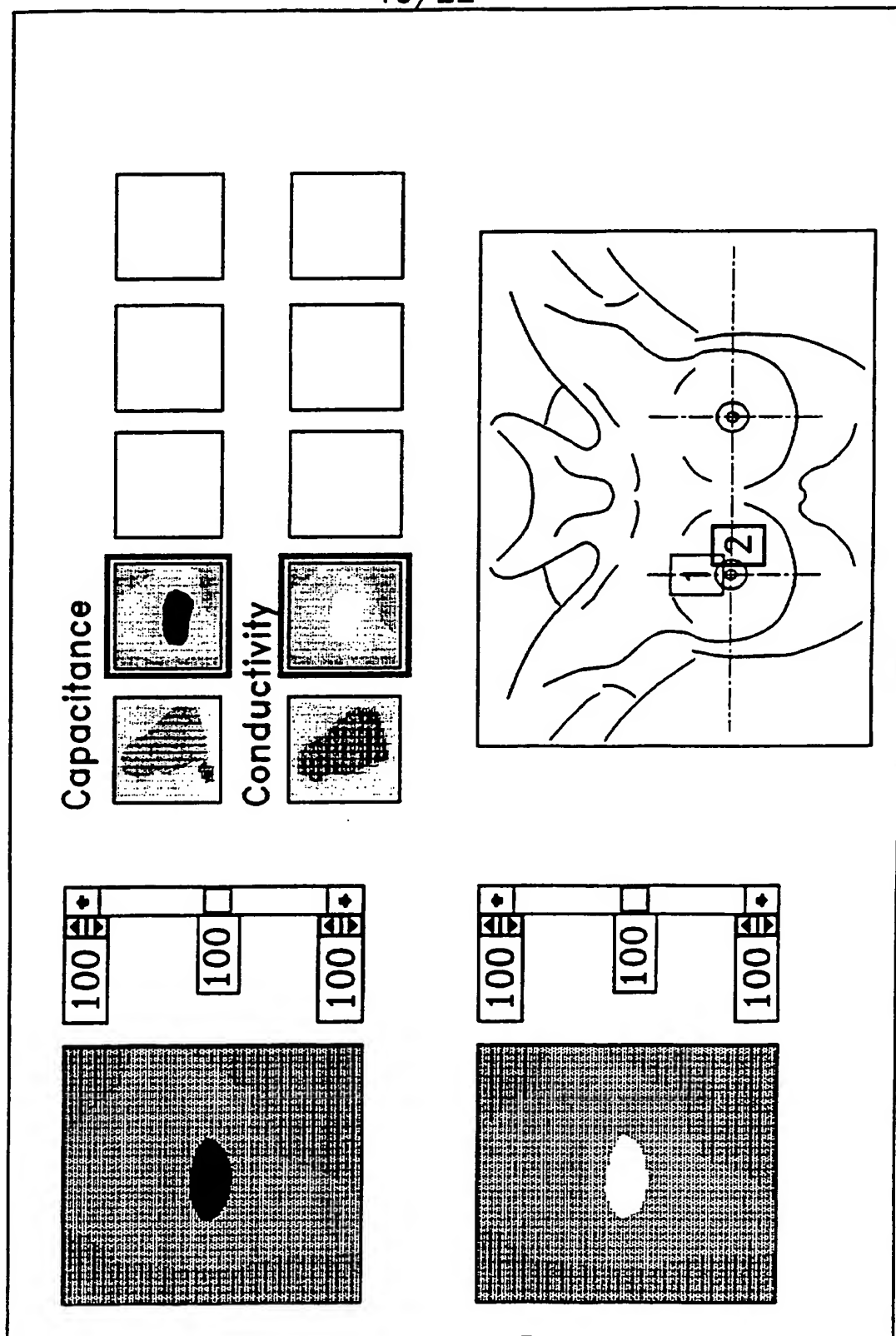
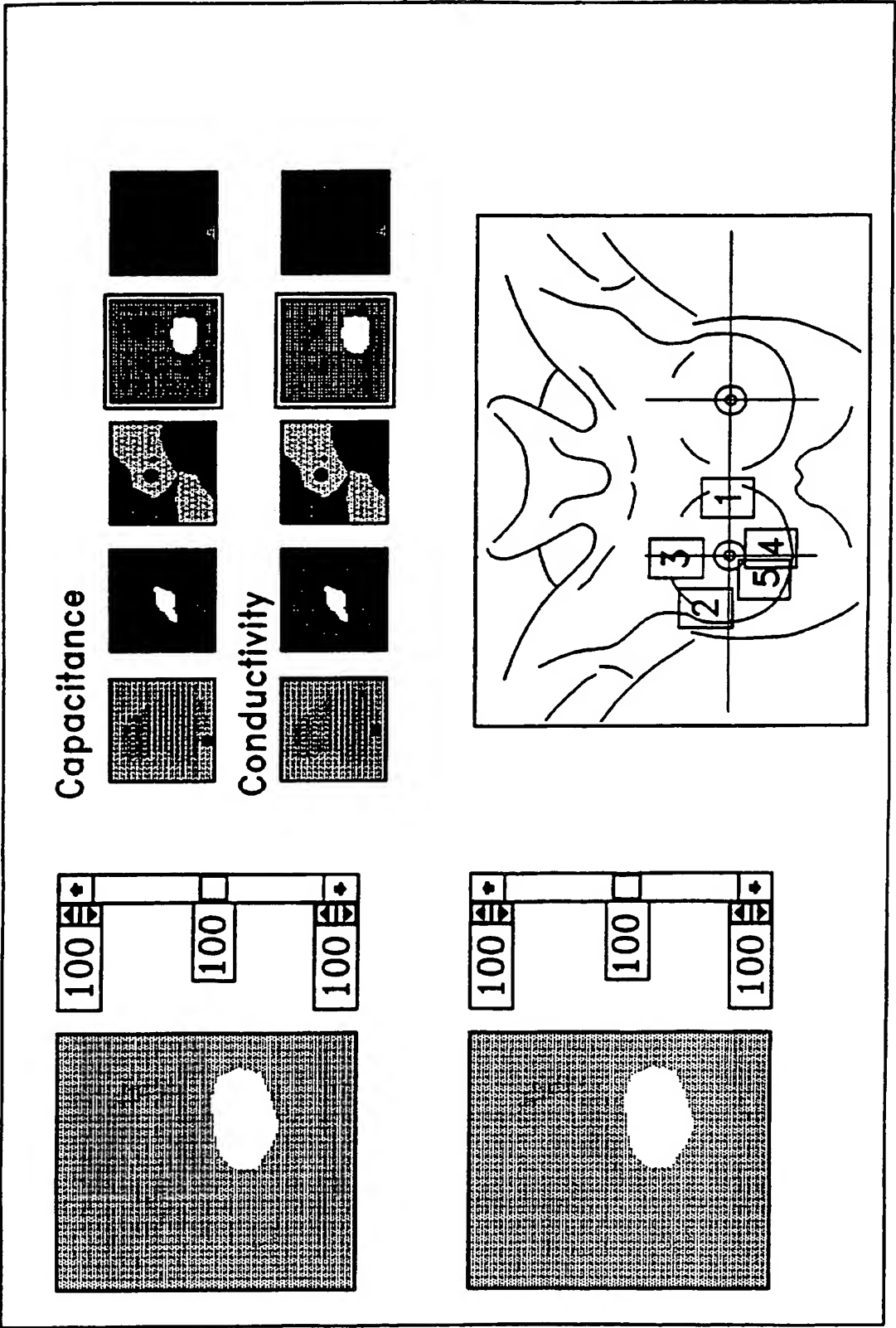


FIG. 15



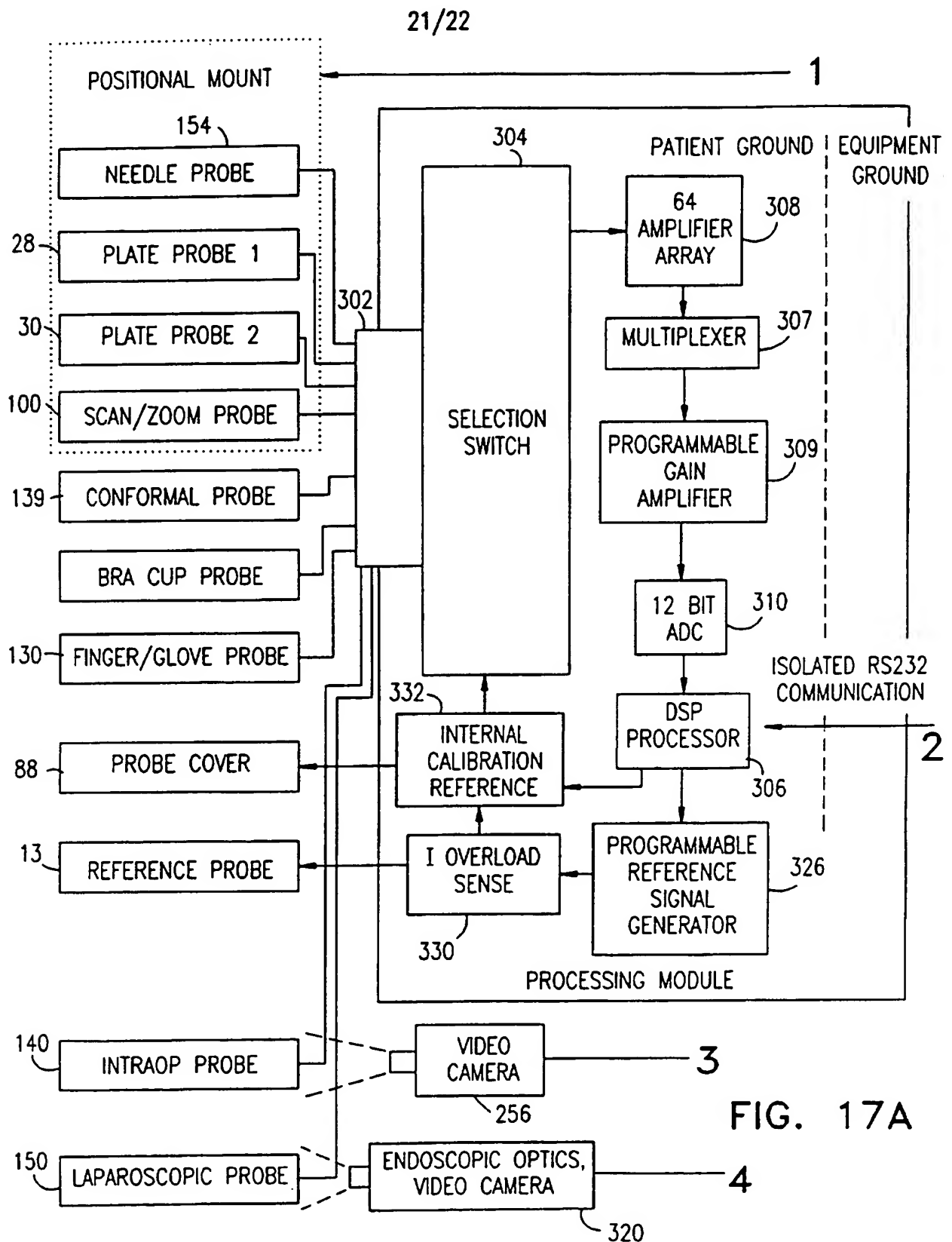


FIG. 17A

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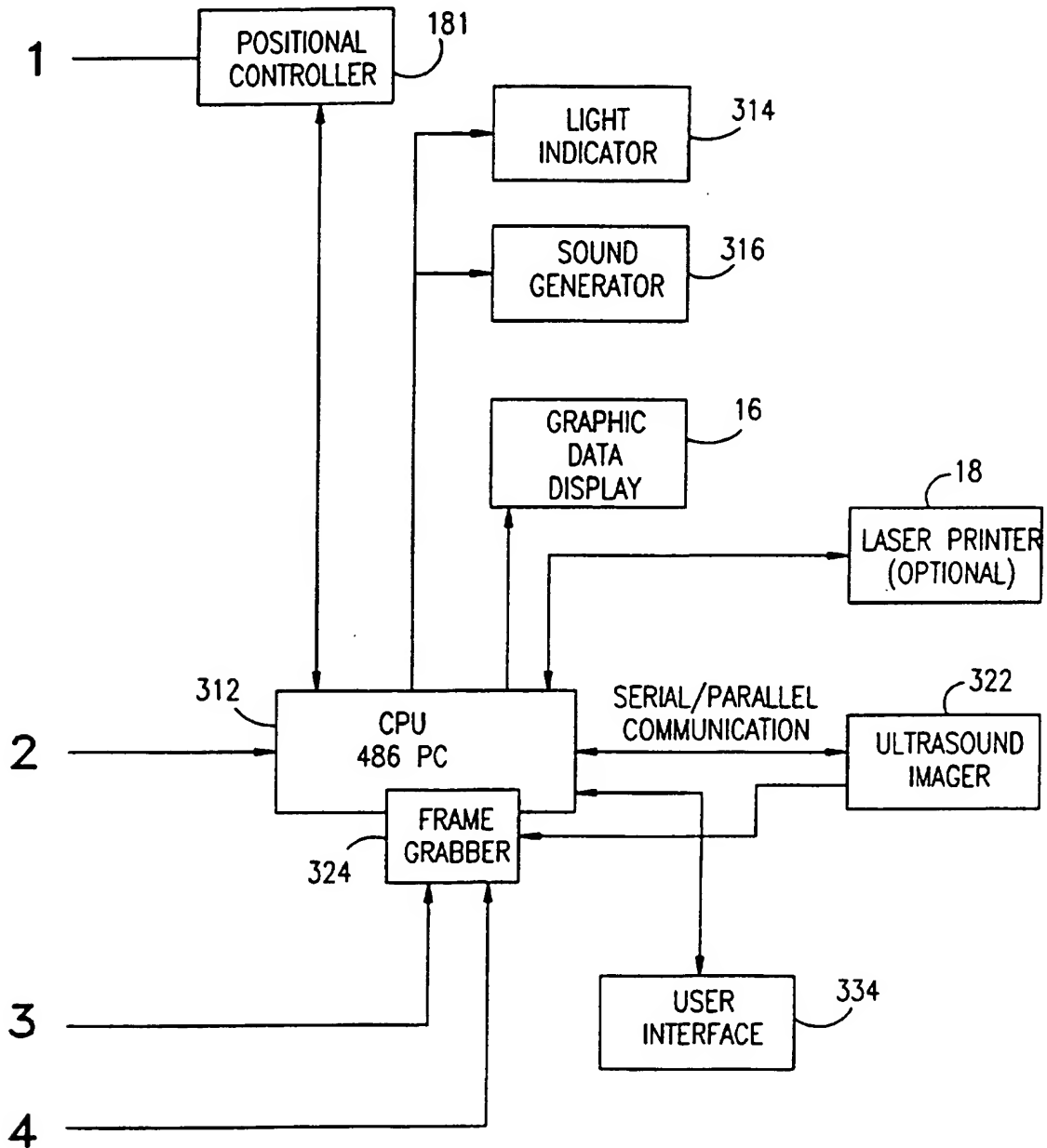


FIG. 17B

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US95/06141

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :A61B 5/05

US CL :128/734

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 128/639, 640, 644, 653.1, 660.01, 660.10, 734, 736

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
NONE

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US, A, 5,143,079 (FREI ET AL.) 01 September 1992, see entire document.	1, 5-8, 11, 14-24, 30, 32-35, 37-40, 43-56, 58-62, 68, 70-73, 76, 77
A	US, A, 4,819,658 (KOLODNER) 11 April 1989, see entire document.	1-82
A	US, A, 5,178,147 (OPHIR ET AL.) 12 January 1993, see entire document.	1-82

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Further documents are listed in the continuation of Box C.

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See patent family annex.

<p>* Special categories of cited documents:</p>		<p>*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p>	
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*P*	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search

21 JULY 1995

Date of mailing of the international search report

07AUG 1995

Name and mailing address of the ISA/US  
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